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REPORT OF A SPECIAL COMMITTEE ON THE CORRELATION OF THE PRE-CAMBRIAN ROCKS OF THE ADIRONDACK MOUNTAINS, THE "ORIGINAL LAURENTIAN AREA" OF CANADA, AND EASTERN ONTARIO

To C. Willard Hayes, Charles R. Van Hise, Albert P. Low and Frank D. Adams, General International Committee on Geological Nomenclature, Representing the Geological Surveys of the United States and Canada:

I. INTRODUCTION

At a meeting of the International Committee on Geological Nomenclature, representing the Geological Surveys of the United States and Canada, held at Ottawa, Canada, on December 31, 1905, it was decided that the subcommittee on the correlation of the pre-Cambrian rocks of the Adirondack Mountains, the original Laurentian area and of eastern Ontario, consisting of President C. R. Van Hise and Professor Frank D. Adams, which had been appointed at the first meeting of the committee, held in Washington on January 2, 1903, should be enlarged by the addition of Professor A. P. Coleman and Professor J. F. Kemp, and that Dr. J. M. Clarke, State Geologist of New York, should be invited to appoint a representative on this committee. Dr. Clarke was subsequently consulted, and appointed Professor H. P. Cushing as representative of the Geological Survey of the State of New York. Dr. Robert Bell was also invited to join the subcommittee. On July 4, when the committee assembled to begin its work, Dr. Bell, being in Europe, was unable to take part

in the work of the committee, and his place was taken by Dr. A. E. Barlow, of the Geological Survey of Canada. Dr. Barlow, however, was able to remain in the field only during a period of about ten days when the committee was at work in the Adirondack Mountains.

Dr. A. W. Spencer, of the United States Geological Survey, accompanied the committee from July 6 to July 23.

This special committee met at Whitehall, N. Y., on July 4, and spent the month of July, 1906, in visiting various districts in the Adirondack Mountains and in the eastern portion of Ontario, with the view of ascertaining, if possible, whether they could agree upon the succession and correlation of the great exposures of pre-Cambrian rocks in these areas, and also upon the nomenclature which should be adopted in the classification of the same.

The mapping of the eastern Adirondack area is now being carried on by J. F. Kemp, and that of the northern Adirondack area by H. P. Cushing and C. H. Smyth, but this work is not as yet completed.

The area visited by the committee in Canada was for the most part that whose mapping has just been completed by F. D. Adams and A. E. Barlow, and which is comprised in the Haliburton and Bancroft sheets of the Ontario series of geological maps being issued by the Geological Survey of Canada, printed copies of the maps in question being supplied to the members of the committee when in the field. The geological report on this area, however, has not as yet been published.

The committee also visited, while in Canada, the Madoc region, which lies to the south and southeast of the area mapped by F. D. Adams and A. E. Barlow. This area was in the early years of the Canadian Survey mapped by Mr. H. G. Vennor, and a portion of it was at a later date mapped on a larger scale by Mr. Eugene Coste.

In making the present report, therefore, the committee wish it to be distinctly understood that in it they are not presenting any new observations made by them in the areas visited, but are merely recording certain facts pointed out to them by Dr. Kemp and Dr. Cushing in the Adirondack area, and by Dr. Adams in eastern Ontario, which will be described in detail in the forthcoming reports by these several gentlemen. To the interpretation of these facts by the gentlemen in question the committee give their full assent, and upon them

base their recommendations for the correlation of these rocks in the several areas under discussion.

II. ITINERARY OF THE COMMITTEE

A. ITINERARY IN THE EASTERN ADIRONDACKS

(Under the guidance of J. F. KEMP)

The committee was summoned to meet in Whitehall, N. Y., on the night of July 4. The first week was devoted to areas which had been mapped by J. F. Kemp in or near the Champlain valley. July 5 the committee, represented by Messrs. Adams and Kemp, reviewed first the green syenitic gneiss in the southwestern portion of Whitehall village, where a massive eruptive rock has become so granulated and platy from crushing and shearing that it strongly resembles sandstone and is quarried like a stratified sediment. Next in the railway cuts north of Comstocks, garnetiferous, thinly foliated, micaceous gneiss was seen, which is believed to be sedimentary. The gneiss was penetrated both by red granite, now rolled out into thinly foliated gneiss with many leaves of quartz, and by a stock or small laccolith of gabbro, which had produced extraordinary rolls in the foliation. Two miles south of Comstocks and just east of the canal two strata of white, crystalline limestone were exposed, of which the lower is seventy-five feet thick, the upper much less. The limestones are associated with black hornblendic gneisses and with granitic gneisses of whose nature, whether sedimentary or igneous, it was not possible to positively decide. From their mineralogical composition they might be either, but the almost constant association with the limestones throughout the area creates a presumption in favor of sediments. The limestone exhibited interesting results of dynamic effects, in dragged and squeezed inclusions of hornblendic schist. In the area between the limestones and Comstocks was the basal Potsdam in a thin coat over the gneiss.

The following day Messrs. Coleman, Cushing, and Spencer joined the others in Whitehall, and all proceeded by the north road across the neck between Lake Champlain and South Bay. The party observed the syenitic gneiss which is believed to penetrate the rusty and somewhat calcareous sedimentary gneisses, and were impressed with the faulted nature of the topography. Crossing

South Bay they traversed platy quartzose, garnetiferous, sedimentary gneisses, with intrusions of gabbro and trap dikes. They observed in the gneiss a development of graphitic schist which has been mined. Proceeding several miles up Pike Brook, the party crossed an outlier of Potsdam sandstone faulted down between the hills of gneiss, and to the southwest on the old State Road saw a ledge of about forty feet of graphitic schist capped by gabbro. Returning, they recrossed South Bay and went over the high ridge to Whitehall, crossing doubtful gneisses, believed, however, to be probably sedimentary. The same evening the party moved to Ticonderoga.

From Ticonderoga, on the following morning, the committee proceeded to Hague on Lake George, and visited the Lakeside graphite mine, where a graphitic quartzite six to ten feet thick is inclosed in garnetiferous, sillimanite gneiss. Still lower are gneisses of quartzose, feldspathic composition. The party then rowed to Flirtation Island, north of Hague, where a gneiss which closely resembles a conglomerate was finally interpreted as one injected with pegmatite stringers and subsequently squeezed. Farther north at Indian Kettles Point a massive, garnetiferous granitic gneiss was seen which was believed to be intrusive. Returning to Hague, the steamer was taken to Rogers Rock, and the party climbed Rogers Slide, a summit about 850 feet above the lake. They crossed much white crystalline limestone, charged with silicates, graphitic pegmatites, and rusty gneisses, until toward the summit they passed to decidedly massive garnetiferous granitic gneiss, similar to the exposures on Indian Kettles Point. All were impressed with its igneous affinities, and attributed the garnets to the influence and contributions of the neighboring limestones. The rock is believed by J. F. Kemp to be an acidic phase of the syenitic eruptives which are normal and abundant in the vicinity. Proceeding to Ticonderoga on foot, the party traversed typical green syenite at the outlet of Lake George, and had no doubt of its eruptive nature.

The next morning the party moved to Port Henry and walked north on the tracks of the railway on the shores of Lake Champlain. Passing across faulted blocks of Beekmantown and perhaps upper Potsdam, they encountered a large intrusion of gabbro. At first gneissoid on the south, the gabbro passes gradually into more massive

phases until it is coarsely diabasic in texture. The gabbro is succeeded by a thick ledge of white crystalline limestone, into which it tongues out with various small apophyses. The limestone is charged with streaks and bunches of silicates, which are contorted in so extreme a degree as to give truly remarkable results of pressure. Farther north quartzose gneisses and more gneissoid gabbro were traversed, the former greatly brecciated by faulting. From the railway the party climbed the hill to the old Cheever magnetite mine and its northward extension. The ore is found as an extended bed, sometimes double, and a half mile or more in length. It is contained in a gneiss, of granitic composition, which has gabbro a short distance below and white crystalline limestone a short distance above. Various opinions were advanced about the nature of the gneiss and the origin of the ore, sedimentary, intrusive, and contact views being all expressed without reaching unanimity. Returning by highway to Port Henry, the party visited the ophicalcite and white limestone quarries lying to the west of the road, and saw the latter rock much cut up by pinched pegmatites and basic stringers.

The following day the committee drove to Mineville, six miles northwest, and on the way visited another quarry in white limestone and the abandoned Pilfershire magnetite mines. The relations of the ore are much the same as at the Cheever, except that heavy drift so masks the exposures below the gneiss forming the wall-rock that their nature cannot be told. At Mineville the party visited the great iron mines and studied the relations with the overlying acidic gneiss and the underlying, generally basic, hornblendic variety. At the belt of ore on Barton Hill it was shown that the underlying hornblendic gneiss passed directly into gabbro. Various views were suggested for the formation of the ore, some favoring igneous segregation, others contact metamorphism, still others replacement or sedimentation; but the problem was too obscure for agreement. In the evening the party was joined by C. R. Van Hise and A. E. Barlow.

The following day the committee again went over the mines and examined the maps which were courteously shown by the chief engineer of the company, and later visited the outlying workings at Cook Shaft and Fisher Hill. The general feeling was that several successive processes might have been involved in producing the ore

in its present form. In the evening all moved to Plattsburg, where H. P. Cushing became the guide.

In the eastern Adirondacks the attempt was made to visit the rocks of actual or probable sedimentary character, rather than the great eruptives of whose nature there is much more certainty.

B. ITINERARY IN THE NORTHERN ADIRONDACKS

(Under the guidance of H. P. CUSHING)

On July 11 the party went from Plattsburg to Tupper Lake, with stops at Dannemora and Saranac. At Dannemora amphibolites were seen, cut by granitic gneisses, and both cut by unmetamorphosed dikes of diabase and syenite porphyry. The locality was typical of a great area in the northern Adirondacks where such a gneiss complex prevails, along with frequent gray gneiss of intermediate composition. The origin of the amphibolite is uncertain. The complex has been called the Saranac gneiss and is precisely like that seen later in many places in Canada.

At Saranac a locality was visited which showed irruptive contact of anorthosite with gneisses which, while themselves of somewhat doubtful nature, are in close association with undoubted Grenville sediments near at hand.

The following day the party drove from Tupper Lake to and through Litchfield Park, seeing the gradation from the typical green syenite along the lake to the reddish, granitic phase of the same rock in the park, and seeing also the red granites, almost wholly quartz-feldspar rocks, which cut the syenite. A small anorthosite outlier was also visited. This is surrounded on all sides by the red syenite, which, as the anorthosite is neared, grades into a basic green syenite which cuts the anorthosite, though the best locality for seeing this was not located. Adams did not accompany the party on this day.

July 13 the committee drove from Tupper Lake to Axton, seeing first green syenite, followed after an interval with no exposures by anorthosite cut up by dikes of varying sizes of a rock which H. P. Cushing believes to be the syenite, and which seemed such to the other members of the party except A. W. Spencer, who expressed some doubt as to the equivalence. Beyond, the route was entirely

in anorthosite, of somewhat gabbroic nature for the most part. Panther Mountain, at the south end of Upper Saranac Lake, which was climbed by the party because of the good view of the general topography of the region obtainable from its summit, furnished a good exhibition of the general character of the anorthosite. Syenite dikes of various sizes persist in the anorthosite with diminishing frequency for a distance of three or four miles from the edge of the mass.

The next day boats were taken at Axton for a trip down the Raquette to Tupper Lake, with a side excursion into Follensby Pond. The anorthosite was found grading from the normal rock at Axton into a basic gabbro near Follensby Pond, adjoined by the syenite in somewhat basic phase, illustrating the general tendency of the anorthosite bathylith to become more basic at its borders, and the similar tendency of the syenite to become more basic in the vicinity of the anorthosite. At the upper end of Follensby Pond Grenville rocks were seen, the outcrops being at the northern extremity of a long belt of these rocks extending unbroken for several miles. Limestone, both pure and impure, rusty graphitic gneiss, and a little quartzite were seen. These and other rocks of the belt are precisely like those seen the preceding week and those seen later in Canada. Down the river from Follensby the rocks seen were anorthosite of the gabbro type followed by syenite.

The rocks of the central area of the Adirondack region consist mainly of bathyliths and smaller masses of anorthosite, syenite, granite, and gabbro, with only occasional patches of the sediments, and the region seen in the three days was a good sample of the general area. The asymmetric differentiation of the syenite into a basic type in the vicinity of the anorthosite, which it cuts, and into an acid type in the contrary direction where it adjoins and cuts granitic gneisses, as well as the local differentiation of the acid syenite into the basic type around an inclusion of anorthosite, seemed to point to the digestion of material from the adjacent rocks as a cause of the differentiation.

Monday, July 16, was mainly taken up in journeying from Tupper Lake to Theresa in Jefferson County, to see there the rocks as they appear in the northwestern region. The evening of July 16 and the whole of the next day were spent in this examination. A thick

limestone formation was seen, and a great thickness of other rocks in thinner beds, including limestones, quartzites, amphibolites, and various gneisses, all of which were cut by dikes and small bosses of granite. The series seems to be sharply folded—so sharply that the prevailing dips are in one direction. The thick limestone was found to be overlain by a great mass of granitic gneiss, under which it seemed to dip, and with no sign of contact action in the limestone, though there were traces of it in the edge of the granite. Some varieties of gneiss somewhat suggest tuffs. The Potsdam is just being worn away from the pre-Cambrian with many patches of it, both large and small, yet in position, showing various conglomerates and a very irregular deposition floor. Near at hand, but not visited, is a large granite bathylith full of amphibolite inclusions, precisely like those seen later near Deloro and Gooderham.

In the evening the party went to Clayton.

C. ITINERARY IN EASTERN ONTARIO

(Under the guidance of F. D. Adams)

The committee then crossed the St. Lawrence into Canada, taking the ferry from Clayton to Kingston, from which latter place they went by train to Tweed.

From here they proceeded to Bridgewater, in order to examine certain conglomerates referred to by Vennor. About half a mile east of Bridgewater they found granite protruding through the drift, which granite was succeeded immediately to the west by a body of amphibolite. In the amphibolite an autoclastic structure was developed in places, which gave rise to an appearance faintly simulating a conglomerate. All the members of the committee, however, agreed that this structure was autoclastic and was of no stratigraphical significance.

Passing by a great development of crystalline limestone with interstratified bands of fine-grained gneissic rocks at the village of Bridgewater, the committee went to a point one and a half miles west of this village, where they found exposed by the side of the road a conglomerate which is undoubtedly of true clastic origin.

This conglomerate is exposed for several miles along the Madoc road, which runs east and west, and a good cross-section of the

conglomerate and the strata with which it is associated was found on the Queensboro road, which crosses the Madoc road at right angles. The conglomerate contains very numerous pebbles of several different kinds of rock. These are as follows:

1. Pink felsite. These are most abundant and form the dominant element of the conglomerate.
2. White quartz, resembling vein quartz.
3. White quartzite.
4. Amphibolite, dark in color and very fine in grain.

To the west of the Queensboro road the conglomerate also holds some pebbles of cherty and ferruginous rocks resembling those found in the iron ranges of the Lake Superior district.

The pebbles of this conglomerate are often quite round, but are usually very considerably flattened. They are sometimes several inches in diameter. The rock shows very considerable variations in size and abundance of the pebbles in different bands, some bands being entirely free from pebbles and resembling a quartzite in appearance. The conglomerate also shows distinct cross-bedding in certain places. It has a nearly vertical attitude, its beds being bent back upon themselves in a series of sharp folds.

On the Queensboro road, to the south of its intersection with the Madoc road, the conglomerate is followed by a dark amphibolite containing a great number of small corrugated quartz veins, presenting a remarkable autoclastic structure and often pinched out into forms closely resembling pebbles. This is succeeded by a series of pink felsites, which in their turn are followed by calcareous amphibolites, and these by crystalline limestones.

The succession on the Queensboro road from north to south, with the approximate thickness of the several occurrences (as exposed), is as follows:

Dark amphibolite, for the most part massive	600 feet +
Conglomerate (probably duplicated by folding)	3,100 "
Amphibolite with quartz veins showing autoclastic structure	?
Pink felsites	352 "
Calcareous amphibolite	935 "
Crystalline limestone	300 " +

Before the conglomerate was laid down it is certain that the

crystalline limestone, the calcareous amphibolite, and the pink felsites were in a condition to yield fragments, that such fragments were well rounded by water action, and that these formations were the chief sources of material for the conglomerate. It therefore follows that there is an important local break between the conglomerate and the underlying formations. However, the district is one in which contemporaneous volcanic action occurred, and when the conglomerate is traced along the strike it appears to contain volcanic clastic material. The question therefore arises whether this conglomerate marks a general uncomformity in the sedimentary series for the district or is a local unconformity. This question can be finally decided only when the Madoc district is mapped in detail.

The committee then went to Deloro, which lies about seven miles to the west of the village of Madoc. In this vicinity they found a large mass of granite, constituting what is locally termed the "Huckleberry Rocks," penetrating a series of highly altered impure crystalline limestones and developing in the latter a great variety of silicates in the form of irregular bands and masses.

A short distance to the north of the village of Deloro the granite was found cutting a dark amphibolite, of which it inclosed an immense number of angular fragments which in places presented distinct evidence of being absorbed by the granite mass. It was not quite clear whether this process of absorption was produced by the complete solution of the amphibolite in the granite and the subsequent recrystallization of the resulting mass, or whether the intermediate rock had resulted from a very complete penetration of the intruded amphibolite by granitic material. According to Mr. Coste, the amphibolite in question results from the alteration of the limestone by the granite mass, but the limited time at the disposal of the committee did not permit them to examine a sufficient area to enable them to satisfy themselves on this point. Some of the amphibolitic masses included in the granite, however, had the appearance of tufaceous material—a fact which is of importance in connection with the question of the origin of the amphibolite as a whole. The committee considers that this granite intrusion presents one of the finest known examples of both exomorphic and endomorphic contact action.

The committee then went north to the village of Bannockburn, about a mile to the southwest of which, on the road, they found a great body of massive diorite or amphibolite in contact with the same limestone series, the two rocks being folded together along their contact. The appearance of this dioritic mass near Bannockburn suggests somewhat, in the traces of ellipsoidal structure which it presents, certain Keewatin rocks of the Lake Superior region.

The committee then visited the district about Millbridge on the Hastings road, where they again found the same limestone series which here, being very free from igneous intrusions, is comparatively unaltered in character and preserves its original blue color. This body of limestone, however, although apparently uniform in character, is seen, on a careful study, especially of the weathered surface to contain many thin, interstratified layers which are much harder than the limestone itself, and which when examined under the microscope are found to be composed almost entirely of silicates, chiefly feldspars, both plagioclase and orthoclase, with quartz and some biotite. The rock composing these layers now shows a perfect "pflaster" or pavement structure, and is completely crystalline. It is, however, of undoubtedly sedimentary origin and has been referred to by Adams as "paragneiss". These bands are of importance as representing in this comparatively unaltered portion of the limestone formation rocks which, when the alteration of the formation is more pronounced, assume a much more distinctive form.

From Millbridge the committee went north on the Hastings road, which, running at right angles to the strike of the rocks, affords a most admirable section through the sedimentary series with its various interstratified rocks, for a distance of thirty miles north of Millbridge, where the sedimentary series becomes torn to pieces by the great invasions of the granite bathyliths to be mentioned later.

About three miles to the north of Millbridge a great intrusion of more or less altered gabbro, about two miles in width, was crossed. This was found to be nearly massive in character and to alter the intruded sedimentary rocks.

Crossing over this intrusion, the limestone series was again encountered, the Hastings road for the next six miles passing over more or less continuous exposures of limestone, interstratified in places

with a considerable volume of bedded amphibolites and fine-grained gneissic rocks which either represent intercalations of muddy sediments analogous to those forming the paragneisses about Millbridge, or have originated from the complete alteration of volcanic ashes which fell into the sea at certain times during the deposition of the limestones. The chemical composition of the majority of these amphibolites is such that they might be derived either from the alteration of calcareous silts or from showers of basic volcanic ashes. The existence of numerous gabbro intrusions, having a more or less rounded outline, in association with this limestone series, more especially where these amphibolite bands are abundant in it, suggests that these represent the bases of volcanic centers from the ejectamenta of which the amphibolites were derived.

Having gone north on the Hastings road as far as Murphy's Corners, the committee then proceeded to Gilmour, a station on the Central Ontario Railway about five miles to the east of the Hastings road, to examine certain conglomerates which are found in that vicinity associated with two bodies of granite which penetrate the limestone series.

The committee considered these conglomerates to be in part of autoclastic origin, and, in all probability, in part of volcanic origin, representing tufaceous material derived from volcanic centers now represented by the masses of granite associated with it. Dr. Barlow, however, who mapped the occurrence, considers them to be of exclusively autoclastic origin. The time at its disposal did not enable the committee to make a detailed examination of the stratigraphical relations of this conglomerate, but after the field-work of the committee was brought to a close, Messrs. Cushing and Adams returned to this locality and re-examined the conglomerates. They found that they were interstratified with limestones, and consequently of the same age as these rocks, and that, on approaching the granite mass lying to the east, these rocks were thrown into a series of very sharp folds, evidently due to their being pressed against the granite mass, and that the granite mass, immediately about its contact with these rocks, exerted a very pronounced exomorphic contact action, changing the limestones for a distance of at least 100 yards into a mass of reddish-green rock consisting of an admixture of epidote, garnet, pyroxene, and

other minerals. The committee therefore considers this conglomerate to be of interformational origin, and to have no special structural significance.

The committee then proceeded by train to Ormsby, where they examined a remarkable development of the limestone series consisting of beds of limestone interstratified with thin bands of amphibolite, displaying a series of very intricate folds. They also examined the Thanet gabbro, a large intrusive mass of approximately circular outline which here breaks through the limestone series, sending dykes into it and including masses of the latter. They also visited the Coehill iron mines, situated about five miles to the west of the village of Ormsby, where a very considerable body of somewhat pyritiferous magnetite is developed in the limestones, here interstratified with amphibolite about the contact of an intrusive mass of syenite.

Between Ormsby and Ormsby Junction the committee saw a great development of the typical rusty gneiss which is so commonly associated with the white crystalline limestones wherever these occur in the area embraced by the work of the committee. The development of these gneisses at this locality is one of the thickest which have hitherto been discovered in this series. Some bands of it resemble in appearance certain varieties of the Magnetite-Grunerite Schist of the Lake Superior iron ranges.

From Ormsby Junction the party went north by railway, passing over a further extension of the limestone series to Bancroft on the York branch of the Madawaska River, and examined the nepheline syenites, which have a very extended development in this district, and which in one locality about two miles and a half on the east of Bancroft are traversed by veins containing large masses of sodalite which are now being worked for decorative purposes.

They then went east to Bronson's Landing and proceeded by canoes down the York branch of the Madawaska to Craigmont, and spent three days in examining the very extensive and highly interesting occurrences of corundum which are here being mined on an extensive scale. This corundum occurs in syenites, most of which are rich in nepheline.

The party then returned to Bancroft and went by the Irondale, Bancroft & Ottawa Railway to Gooderham, stopping on the way to

examine a large deposit of biotite, formerly worked at this point, and which occurs in a granular, green pyroxenite which represents an altered limestone, near Wilberforce station. The limestone band is here highly altered, owing to the fact that it lies between two great bathyliths of granite.

At Gooderham the committee studied the relation of the limestone series to one of the great bathylith intrusions which form the northern portion of the area mapped by F. D. Adams and A. E. Barlow. This, which is known as the Glamorgan bathylith, is here ten miles wide and is completely surrounded by the limestone series through which it breaks. They first examined the eastern margin of the bathylith. Starting from the normal development of the limestone series on the line between the townships of Glamorgan and Monmouth, they went westward toward the bathylith, following the Ursa road. They found the limestone series became penetrated by dykes of granite in ever-increasing numbers, becoming eventually torn into fragments which lay thickly scattered in the granite forming the margin of the bathylith. It was noted that the limestone on going toward the granite became progressively more impure, being apparently replaced by amphibolite, and that but few fragments of limestone could be found among the inclusions of the granite itself.

The committee then examined the southern contact of the bathylith in the railway cutting at Maxwell's Crossing on the Irondale, Bancroft & Ottawa Railway. Here they found undoubted evidence that the limestone was being changed by the granite, first into a rock composed of pyroxene, plagioclase feldspar, scapolite, and calcite, and then, when the action was more intense, by a further change into a gray amphibolite consisting of hornblende, pyroxene, and feldspar, the latter dominantly plagioclase. The committee are of the opinion that the evidence is indisputable that the granite bathyliths in this region change the invaded limestone into a dark-gray amphibolite, which, together with the fragments of the interbanded amphibolites found everywhere in the limestone series, occurs scattered throughout the granite mass in the form of included fragments. By this statement it is not meant to imply that all of the amphibolites of the district are derived from the metamorphism of limestones, for in some places the amphibolites appear to be metamorphosed

pyroclastic material, and in other places they originate from the metamorphism of intrusive basic igneous rocks. One of the chief difficulties solved in the study of the district by Adams was the recognition of the fact that the amphibolites had such diverse origins.

In the vicinity of Gooderham the committee also examined a large occurrence of titaniferous iron ore representing a differentiation product of a large gabbro intrusion which occurs to the south of Gooderham. This iron ore is situated on lot 35 of Range IV of the township of Glamorgan. They also saw several occurrences of graphite in the limestone series in this vicinity and examined three occurrences of nepheline syenite which are here found penetrating the limestone series. These nepheline syenites hold in many places inclusions of calcite, often of microscopic dimensions, which are clearly fragments of the limestones in which the nepheline syenites occur.

Leaving Gooderham, the party went north across the entire width of the Glamorgan bathylith to Haliburton. They found the bathylithic mass to form an area of very rough country, unlike that underlain by the limestone series. They also found the bathylith to consist chiefly of a fine-grained reddish gneissic granite, very poor in iron magnesia constituents. This, however, contained almost everywhere numerous inclusions of several varieties of amphibolite which the committee believe can be clearly proved, as held by Adams and Barlow, to represent fragments of the invaded limestone series. In addition to these there are considerable bodies of a grayish gneiss, which are believed to represent amphibolite inclusions which have been entirely absorbed or dissolved by the granite magma. It was stated by Adams that throughout the whole great area to the north of the district examined by the committee the bathylithic masses of granite were filled with similar inclusions. He estimates that these bathyliths on an average consist of about 80 per cent. of the red granite, 10 per cent. of the gray gneiss, and 10 per cent. of amphibolite inclusions, resulting in the way above mentioned.

About Haliburton the committee found the limestone series appearing in great force, developed in some places as great cliffs of white marble. This limestone can be traced continuously around the east end of the bathylith to the Ursa road and to Maxwell's Crossing,

where the committee formerly examined it. To the north of Haliburton it is flanked by another bathylithic mass similar to that just described.

In this connection it should be remarked that, while the sedimentary rocks of this district have been referred to as the limestone series, this name has been adopted because in this series limestone is the dominant rock. The limestone is, however, commonly impure, not infrequently passing into phases in which the non-calcareous sediments are important or even dominant. Locally the sediments were apparently of the nature of altered volcanic fragmental material. This heterogeneity of original composition naturally leads to very great variety in the metamorphosed products, which vary from gneiss through calcareous schists to marbles and several varieties of amphibolites.

At Haliburton the field-work of the committee was brought to a close.

III. RÉSUMÉ OF THE GEOLOGY OF THE ADIRONDACK AREA

So far as known, the oldest series of rocks in the Adirondack area consists of strongly and coarsely crystalline limestones, ophicalcites, quartzites, quartz-schists, rusty, micaceous, thinly foliated gneisses and more massive gneisses. Among these the limestones are on the whole the ones most easily recognized. On the east they are well and prominently developed. In the central area they seem to be extensive, but are poorly exposed, and quartz schists are prominent. On the northwest they appear in largest amount and form continuous belts over long distances. The limestones are usually charged with bunches and streaks of silicates, which are in part torn and sheared intrusives, in part pegmatites, and probably also in part former siliceous, ferruginous, aluminous bands.

The quartzites on the east are best developed near South Bay, one of the two southern arms of Lake Champlain. They are thoroughly recrystallized, and all original clastic structure has been destroyed. They may contain great proportions of feldspar, and may also have sufficiently large percentages of graphite to be mined for this mineral. These feldspathic varieties were doubtless originally shales.

Rusty micaceous rocks with a peculiar yellow color on exposed surfaces are also frequent, although not in great thickness. They and other schistose, micaceous gneisses are believed to be recrystallized sediments.

Beneath the above, and sometimes interstratified with them, are more massive gneisses of a general granitic composition. While quartz and feldspar are the principal minerals, dark silicates also appear of the following kinds: emerald-green augite, brown hornblende, and biotite. Several varieties of gneiss are known depending on the relative proportions of these minerals. The iron ores are associated with them in almost all cases. It is a doubtful point as to whether these gneisses are in any cases sediments. They may be mashed, intrusive, granitic rocks in which the foliation is secondary, or they may be extreme phases in the metamorphism of arkoses or acidic volcanic tuffs.

In the Adirondack Mountains the series is invaded by enormous bodies of intrusive rock (anorthosite, gabbro, syenite, etc.), so that the sedimentary portion of the series forms a relatively smaller proportion of the whole complex than in the other areas covered by the work of the committee.

The undoubted sediments and their associated gneisses of uncertain origin are penetrated by several varieties of plutonic eruptives. The oldest constitute the anorthosite series, and embrace rocks from aggregates of nearly pure plagioclase to fairly rich mixtures of augite, hypersthene, and ilmenite with the plagioclase. The borders of the great bathyliths tend to be more basic than the centers.

The next in time among the intrusives constitute the syenite series. The typical rocks consist of microperthite, augite, hornblende, biotite, and varying amounts of quartz. Subordinate varieties are as rich in quartz as typical granites. Near the contacts with anorthosites and limestones garnets become numerous.

The third eruptive series consists of typical granites of both hornblendic and micaceous varieties. Areally the granites are of small extent, but they appear in scattered exposures outside the anorthosites.

The fourth series consists of dark basic gabbros, which are certainly later than the others, except perhaps the granites. No intersections with the latter are known. The basic gabbros appear in

wide distribution throughout the area, and form dikes, stocks, and small laccoliths.

All these intrusives preceded a great period of metamorphism. Following it and still antedating the Potsdam, there entered two series of narrow dikes: one of basaltic rocks, which are very widely distributed, and a minor set of syenite-porphyry.

The oldest Paleozoic sediment anywhere in the Adirondacks is the Potsdam sandstone.

From the above it is evident that in this area the pre-Cambrian formations are practically the same as those in the neighboring parts of Ontario and Quebec.

IV. RÉSUMÉ OF THE GEOLOGY OF THE EASTERN ONTARIO AREA

The area presents an immense development of highly metamorphosed rocks, for the most part of sedimentary origin. Among these limestones preponderate. These limestones in the southern portion of the area, where the metamorphism is less intense, are often fine in grain and drab or bluish in color. On going north, however, there is a progressive increase in the intensity of metamorphism, and the limestones gradually lose their color and become coarser in grain, eventually developing into coarsely crystalline white marbles, generally more or less impure.

Interstratified with these limestones are non-calcareous rocks, among which fine-grained, often more or less rusty weathering gneisses and a variety of amphibolites are the most important and the most abundant. A few bands of quartzite also occur, although in this area these are distinctly subordinate

These gneisses certainly represent highly altered and recrystallized sediments, more or less argillaceous in character. The quartzites are in the majority of instances altered arenaceous sediments. Adams has shown that the amphibolites have a threefold origin. Certain of them represent limestones which have been altered by invading granites; others have been produced by the dynamic alteration of basic igneous intrusions; while still others have in all probability resulted from the recrystallization of basic fragmental volcanic material. The remarkable fact is that all these processes produce amphibolites which cannot be distinguished from one another

either by appearance or by chemical analysis. The discovery of their genetic relations affords the key to the solution of some of the most important problems presented by this and other similar areas.

The relative abundance of the limestones and their associated gneisses and amphibolites varies from place to place. In some parts of the area there are enormous developments of nearly pure limestones. Elsewhere these are very impure, while in some places there are great thicknesses of amphibolites and gneisses entirely free from limestones.

The limestones with their interstratified and bedded amphibolites are usually steeply inclined, although in certain parts of the area they keep a nearly horizontal attitude.

The thickness of the series cannot be determined, but it is very great. It is one of the thickest pre-Cambrian series in North America.

Along its whole northern border this sedimentary series is torn to pieces by an enormous volume of gneissic granite of igneous origin which rises from beneath it, and which along its margin also wells up through it in the form of great intrusive bathyliths. This is filled with included fragments of the invaded series, limestones altered to amphibolites, fragments torn from interstratified bands of amphibolite, or of sedimentary gneiss, being scattered through it everywhere and being sometimes found in a more or less digested condition.

The base of the series has nowhere been found. Wherever its lower surface can be seen, it rests on great masses of the gneissic granite, which are intrusive into it and which, as has been mentioned, rise through it in the form of bathyliths.

In addition to the granite intrusions, around the border of which in many places there are occurrences of nepheline syenite which afford one of the most interesting studies in the area, there are also several larger and a number of smaller intrusions of a basic gabbro and gabbro-diorite. These often show a wide range of magmatic differentiation.

There are also a few smaller intrusions of anorthosite in the western part of the area, but these are distinctly subordinate.

A few small intrusions of typical granite also occur, one of which in the township of Lake, forms the center of a development of acidic lavas and apparently represents the plutonic plug of an ancient volcano.

Whether these intrusions of gabbro antedate those of the granite cannot be determined with certainty, as the two sets of occurrences are not found in contact.

In Logan's original examination of the southern portion of the area he used the designation "Hastings series" for the less altered portion of the series, and the term "Grenville" for the more highly altered portion. He expressed the opinion, however, at the time, that the Hastings series in all probability represented the Grenville series in a less highly altered form.

V. RÉSUMÉ OF THE GEOLOGY OF THE "ORIGINAL LAURENTAIN AREA" AND ITS EASTERLY CONTINUATION IN THE DISTRICT TO THE NORTH OF THE ISLAND OF MONTREAL

It has been thought well to make reference here to the "Original Laurentian area" and to its easterly continuation to the north of the island of Montreal. The committee did not examine these districts, but the former was studied by Sir William Logan in the early years of the Canadian Survey, a map of it having been published in the atlas accompanying the report of the survey for 1863, while the latter district was studied by F. D. Adams, his report and map of it appearing in 1896. As the studies in these districts have played an important part in shaping the nomenclature adopted in the case of the pre-Cambrian rocks of eastern America, the committee requested Dr. Adams to prepare the following brief description of them.

The "Original Laurentian area" of Logan lies in the province of Quebec, on the north shore of the Ottawa River, between the city of Montreal and the city of Ottawa, and takes its name from the township of Grenville and the village of that name, which lie within it. The second area mentioned forms the continuation of this "Original Laurentian area" to the east, and embraces the district about St. Jerome and eastward nearly as far as the St. Maurice River. There is every reason to believe that the area embraced by these two districts represents the continuation of the pre-Cambrian series studied by the committee in eastern Ontario, seeing that both occupy precisely the same relative position along the southern margin of the protaxis and that rocks similar to them in petrographical char-

acter occur in the intervening tract of country. In the development of these rocks in the province of Quebec, however, the "Hastings" facies (see p. 201) is absent, the rocks being all highly altered, and resembling in this way those found in the Adirondack Mountains and in the more altered portion of the Ontario district.

The "Original Laurentian area" and its easterly continuation above mentioned, like the area in eastern Ontario, occupy the southern portion of the Laurentian peneplain, underlying a great tract of slightly undulating country. They are composed of great bands of limestone interstratified with amphibolite and rusty weathering gneiss, often highly garnetiferous. This rusty weathering gneiss, where it occurs typically developed in the district about St. Jean de Matha, is found to be rich in sillimanite and to have the chemical composition of an ordinary clay slate. Bands of quartzite are also present in a number of localities, being interstratified with the gneisses and limestones above mentioned. Limestone, however, is the dominant rock of the sedimentary series.

In Logan's "Original Laurentian area" this distinctly sedimentary series occurs in great folds, the horizons marked by the limestone bands, as mapped by Logan, striking across the country in a series of great sweeping curves. The large bodies of orthoclase gneiss which are present in the district and which Logan considered to form part of the sedimentary series, a more detailed examination in view of recent discoveries would probably show to belong to the lower igneous gneisses and to be of intrusive origin.

Farther east, in the district to the north of the island of Montreal the limestone series is not always so sharply folded, and in one portion of the district, over an area of about 750 square miles, it lies nearly flat, low quaquaversal dips being everywhere observed, the attitude of the beds suggesting that the whole series originally floated on a great body of the underlying granite gneiss. This farther north comes to the surface, the limestone series being torn to pieces by it, and the bathyliths thus emerging being traceable over great areas, the foliation of the gneiss presenting great sweeping curves to which the courses of the lakes and rivers in this northern country conform. It will, therefore, be seen that in all its features this development of these pre-Cambrian rocks in the province of Quebec

conforms to those which have already been described from the areas visited by the committee.

In the eastern part of the original Laurentian area Logan found a large mass of anorthosite, which may be termed the "Morin anorthosite." This formed the eastern limit of the area which he mapped. This anorthosite he found to be in some places more or less distinctly foliated, which foliation he regarded as a survival of an almost obliterated bedding. He furthermore found that the limestone bands in the sedimentary series disappeared on coming against this mass of anorthosite. From these two facts he concluded that the anorthosite belonged to an unconformable, although highly metamorphosed, sedimentary series, which unconformably overlay the Grenville series, whose limestones he considered to pass beneath the anorthosite mass.

Adams, in continuing Logan's work to the east, had occasion to map and thoroughly study this anorthosite body. He found it to have the shape of a clover leaf and to have an area of 990 square miles. The anorthosite in the central portion, and over the greater part of the western half of the mass, is nearly massive, although often showing an indistinct brecciated structure. On going from the center of the mass toward its eastern boundary, however, this brecciated structure becomes more and more pronounced, the angular fragments being imbedded in a progressively larger amount of granulated ground-mass, while along the eastern border the mass becomes perfectly foliated, the angular fragments disappearing almost entirely. These angular fragments and the ground-mass are identical in composition, both being composed essentially of plagioclase. The fragments represent portions of the original coarsely crystalline rock in an uncrushed condition, the ground-mass being produced by the granulation and breaking-down of the original rock, of which the brecciated fragments are the surviving remnants. The fragments in the breccia, like the rock when in a massive form, are deep-blue in color, while the granulated rock has lost this blue color and is gray, sometimes nearly white. This is due to the disappearance of the minute inclusions so abundant in the plagioclase feldspar of all these anorthosites which have not been crushed. Where the rock becomes perfectly foliated, as along the eastern border of the anortho-

site mass, and especially in the narrow extension running off from the southern part of the area and representing the stalk of the clover leaf, the rock becomes perfectly white in color, so closely resembling a saccharoidal marble that the two can be distinguished only on making a trial of their hardness.

A detailed stratigraphical study of this mass proved undoubtedly that it was an igneous intrusion which had broken through the Grenville series, cutting off the limestone bands of the latter instead of covering them up, and which had been subsequently granulated by great pressure brought to bear upon the whole region from the east, seeing that it is on that side that the mass is most intensely granulated, while on the west granulation is confined to the immediate border of the mass.

With regard to the petrographic character of this anorthosite, it may be stated that it is composed almost exclusively of labradorite; augite, hypersthene, and a little iron ore being the other constituents. It is identical in character with most of the other anorthosite masses in the Laurentian of Canada. Hunt, in his early investigations of these rocks, stated that three-quarters of the anorthosite ooccurrences in Canada did not hold over 5 per cent. of minerals other than plagioclase.

It is to be noted that the foliation of the anorthosite, which is a secondary structure due to pressure, was already completed in pre-Potsdam times, for the perfectly foliated rock is overlain by horizontal beds of the sandstone in question.

In addition to this great intrusion of anorthosite, there are twelve smaller intrusions similar in character occuring in the area mapped by Adams.

In addition to these anorthosite intrusions, the sedimentary series, in the original area and in its extension to the east, is penetrated by several intrusions of more acid rocks. One of these consists of a mass of syenite which occurs in the township of Grenville and has an area of about thirty square miles, which is in its turn penetrated by a small body of feldspar porphyry, sometimes holding a small amount of quartz.

Another acid intrusion is represented by the great body of granite, in places developed in the form of coarse augen gneiss, which occurs

about twenty-five miles to the east of the Morin anorthosite intrusion. This possesses the ordinary character of such granitic rocks.

More especially in the southern portion of the "original Laurentian area" there also occur a great number of basic dikes, consisting for the most part of diabase, which represent, as a general rule, the latest intrusions of the district, and which persist across the front of the whole area from west of Grenville to a point north of the island of Montreal, where they disappear beneath the Ordovician cover. These diabase dikes were, however, considered by Logan to be older than the intrusion of syenite in the Grenville district already mentioned, which, in its turn, was older than the porphyry intrusion which cut it. While, therefore, in this original Laurentian area and its eastward extension there is not so great a relative proportion of rocks which are clearly of intrusive origin as in the case of the Adirondack area, intrusive rocks in very considerable variety and of the same general types are represented.

It is worthy of mention that in the Laurentian protaxis still farther to the east, in the district to the north of the Gulf of St. Lawrence and in the Labrador peninsula, a number of anorthosite intrusions of gigantic extent occur. Among these may be mentioned more especially one which may be referred to as the "Saguenay anorthosite," on account of the fact that it is developed about the head waters of this river. This, which resembles the Morin anorthosite in character, has an area of not less than 5,800 square miles. Another enormous area is traversed by the Moisie River, the Clearwater, a tributary of the Moisie, running through a great canyon in this anorthosite. Still others of similar extent might be mentioned. The occurrences of anorthosite which are now known to exist in the Labrador peninsula represent a total area of nearly 50,000 square miles.

As a result of his studies in the Grenville region, Logan announced his belief that the Laurentian system consisted of two great unconformable series of sedimentary rocks, to which he gave the names "Upper Laurentian" and "Lower Laurentian." The latter he considered to be again divisible into a lower and upper portion, which subdivisions he considered to be probably conformable to one another. In the course of time these several series came to be known

respectively as the "Anorthosite" or "Norian" series, the "Grenville" series, and the "Fundamental" or "Ottawa Gneiss." Logan's classification may thus be represented as follows:

Upper Laurentian	. . . . .	Anorthosite or Norian Series
Lower Laurentian	Upper Portion . . .	Grenville Series
	Lower Portion . . .	Fundamental or Ottawa Gneiss

The subsequent investigations by Adams in the district to the east of that studied by Logan showed that the Anorthosite (or Logan's Upper Laurentian series) really consisted of great intrusions, and that the associated limestones, etc., assigned by Logan to the "Upper Laurentian" were really part of the Grenville series. There therefore exist in these pre-Cambrian areas of the province of Quebec two divisions, namely, the Grenville series and the underlying Fundamental Gneiss. The relations of these have not been worked out in such detail as in the case of the Ontario area, but it is believed that here also the Fundamental Gneiss comes against the Grenville series with an intrusive contact.

VI. RECOMMENDATIONS OF THE COMMITTEE CONCERNING CORRELATION AND NOMENCLATURE

The committee considers that over the whole area covered by their investigations—namely, the Adirondack Mountains, that portion of eastern Ontario which they examined, the "original Laurentian area" in the province of Quebec and its continuation to the east as far as the river St. Maurice—the pre-Cambrian sedimentary development is represented by one great series. This series is essentially identical in petrographical character throughout the whole region.

The only locality where the possible (Coleman would say probable) existence of a second uncomformable sedimentary series was suggested by the facts observed, was that on the Queensboro road, east of Madoc, Ontario. It is, however, still a matter of uncertainty as to whether the conglomerate here developed marks the base of an overlying, infolded, uncomformable series or not.

In Logan's original classification of the Laurentian this term—apart from the Upper Laurentian which was proved to be composed essentially of anorthosite intrusions—included two series differing in character, namely, the Lower Orthoclase (Fundamental) Gneiss

and the Grenville series. Now that investigations have shown that these two series differ in origin, one being essentially a great development of very ancient sediments, and the other consisting of great bodies of igneous rock intruded through them, it becomes necessary to separate these two developments in drawing up a scheme of classification.

As the great intrusions of gneissic granite, forming what has been termed the "fundamental gneiss," have an enormously greater areal development than the overlying sedimentary series, constituting, as they do, a very large part of the whole northern protaxis, the committee recommend that the term "Laurentian" be restricted to this great development of igneous gneisses. The nomenclature suggested for the pre-Cambrian rocks of this eastern region will thus conform, so far as the use of this term is involved, with that suggested by the Special Committee for the Lake Superior region.[1]

For the overlying sedimentary series the committee recommend the adoption of the name "Grenville series," as it is the name originally given by Logan to the series as typically developed about the township of Grenville in the "Original Laurentian area" on the north shore of the Ottawa River, in the Province of Quebec, between the cities of Montreal and Ottawa. The term "Hastings series" in the opinion of the committee should be abandoned as a serial name, seeing that the development to which this name was applied by Logan is merely the Grenville series in a less altered form, as Logan in giving the name had conjectured was probably the case. The committee, however, think that it may in some cases be advantageously employed as a qualifying term to designate the less highly altered phase of the Grenville series, which may thus be referred to as the "Hastings phase" of the Grenville series.

In Canada this Grenville series everywhere on going north is invaded by and frays away into the great Laurentian bathyliths, while in the Adirondacks it is cut to pieces by the great intrusions of that area which, when worked out in detail, may prove also to have a more or less similar bathylithic form.

The following succession in this region is therefore recognized and adopted by the committee:

[1] See *Journal of Geology*, February–March, 1905.

Cambrian—Potsdam sandstones, etc.
(Unconformity)
Pre-Cambrian
Grenville series
(Intrusive contact)
Laurentian

The committee consider that it is inadvisable in the present state of our knowledge to attempt any correlation of the Grenville series with the Huronian or Keewatin, so extensively developed in the region of the Great Lakes. The Grenville series has not as yet been found in contact with either of these, and until this has been done and the relations of the several series have been carefully studied, their relative stratigraphical position must remain a mere matter of conjecture.

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THE SEDIMENTARY BELT OF THE COAST OF BRAZIL

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INTRODUCTION.
Location of the belt.
Early references.
Division into Cretaceous and Tertiary.
Doubts regarding the division.
DISCUSSION OF FOSSILIFEROUS LOCALITIES.
The Sergipe district.
The Pernambuco district.
The Parahyba district.
The Rio Grande do Norte district.
The Pará district.
The Bahia district.
The Marahú district.
The Ilheos district.
The Abrolhos district.
The Alagoas district.
The interior districts.
SUMMARY.

From a geological point of view the coast of Brazil can be divided into two principal sections according to the character of the highlands that either abut directly on the beach or at a moderate distance from it rise above the low costal plains, composed of sand flats and tidal- and fresh-water marshes, which are evidently of comparatively recent origin. In the southern section, extending from Cape Frio to the southern limit of the republic (this section might without impropriety be extended to the northern limit of the La Plata estuary) and embracing about one-third of the entire coast line, these highlands are composed of ancient metamorphic and eruptive rocks which are presumably of Archean or early Paleozoic age.[1]

[1] The only known exception is a comparatively short stretch of coast near the Porto de Torres, close to the northern boundary of the state of Rio Grande do Sul, where sandstones and eruptives of late Paleozoic or early Mesozoic age (Permian or Triassic, presumably the latter) abut on the coast.

In the northern section from Cape Frio to the southern mouth of the Amazonas (perhaps also the northern limit of Brazil) the highlands on or immediately back of the coast are, for the most part, composed of horizontal, or approximately horizontal, sedimentary beds of sandstone, shales, and clays, and more rarely of limestone. This costal belt of sedimentary rocks is usually quite narrow, and nowhere does it extend more than a few scores of kilometers from the coast. In the comparatively few and short stretches of coast where it is lacking—as at Cape Santo Agostinho and near Tamandaré in the state of Pernambuco, Bahia and Ilheos in the state of Bahia, and several points on the coast of Espirito Santo and Rio de Janeiro between the mouth of the Rio Doce and Cape Frio—it appears probable that it has been denuded away rather than that it was originally lacking. Its elevation is usually under one hundred meters, but in one district at least (near Alagoinhas in the state of Bahia) it is known to rise to an elevation of about 400 meters.

Although frequent references to local occurrences of this sedimentary belt are to be found in earlier writers,[1] the first geological contribution of value relating to it was made in 1850 by Allport (**5**), who described the occurrence of fossiliferous beds at Bahia containing carbonized wood, cyprids, fish and reptile remains, and fresh-water mollusks that were referred to the Cretaceous age. The first general account of the belt was, however, given in 1870, by Hartt (**4**) who had personally traced it from Cape Frio to Pernambuco. After discriminating the recent consolidated beaches or stone reefs, which are so frequent on this coast and so liable to mislead the geologist, Hartt

[1] In 1811 Feldner, a German engineer in the employ of the Brazilian government, made explorations for coal in this belt, which were based on the occurrence of fragments of carbonized wood in the neighborhood of Bahia. Spix and Martius (**1**) briefly described some of its outcrops of Bahia and near Ilheos, considering those at the former place as of recent formation and those at the latter as equivalent to the European *Quadersandstein*. The identification in the latter case was evidently based solely on lithological resemblances, and in the former on fossils supposed to come from its rocks which were evidently confounded with those of the consolidated beach, or stone reef, later described by Hartt (**4**) and Branner (**11**)—a not unnatural error. Pissis (**3**) in 1842 mapped quite acccurately the Bahia basin as extending down the coast to beyond Marahú, but, misled by shells from the above-mentioned consolidated beach, or more probably and less excusably by the shell-heaps on the island of Itaparica described by Rathbun (**9**) which he erroneously attributed to the section at Monserrate Point, he determined the formation as Tertiary.

referred the beds of the sedimentary belt proper to the Cretaceous and the Tertiary; the former represented by several detached and somewhat disturbed basins of the fossiliferous sandstones, shales, and limestones; the latter, by more widespread and continuous undisturbed (except perhaps by vertical movements) beds of soft sands and clays which clearly overlie the fossiliferous ones. The recognized fossiliferous (Cretaceous) basins were on the Abrolhos islands(with indeterminable plant and fish remains, and associated with eruptive rocks that are not known elsewhere in the belt), at Bahia and vicinity, near Maroim, Propriá, and Santa Luzia in the state of Sergipe, and, based on information that was afterward proved to be reliable, near Pernambuco and Parahyba. Of these basins, those of the Abrolhos and Bahia are of fresh (or brackish) water origin, the others being marine. From the Mariom district a number of typical Cretaceous fossils were obtained and described, but for the other localities no critical study of the fossils was made. Aside from lithological differences, Hartt's principal criterion for discriminating the Cretaceous from the Tertiary, which had not afforded fossils, was the somewhat disturbed position of the former while the beds referred to the latter are undisturbed.

In his expedition to the Amazonas in 1870, immediately after the publication of his book, Hartt dispatched two of his assistants, of whom the present writer was one, to Pernambuco to examine the fossiliferous locality reported near that place. The result was a small collection from the limestone rock of the small river Maria Farinha, a few miles north of the city, which were described by Mr. Rathbun (**6**), who referred them to the Cretaceous, without, however, finding any forms decidedly characteristic of that age. In 1875 Hartt personally visited the locality, accompanied, among others, by Dr. J. C. Branner, and secured a large and varied collection for the Geological Commission of Brazil, of which he was chief. In the following year Branner made a careful examination of the Sergipe basin,where a large collection was also made. In the same year the present writer obtained through a friend, a few blocks of highly fossiliferous limestone from the river Pirabas (by error this name was given as Piabas in the notes furnished to Dr. White (**10**) for his monograph on the Brazilian fossils), just south of the southern mouth of the Amazonas, containing a number of species

identical with those of the Pernambuco basin. Some years later he was shown fragments of fossiliferous limestone from near Mossoró, in the state of Rio Grande do Norte, that indicated the existence of another similar marine basin in that region; and recently Branner (**12**) has shown that a fresh-water formation similar to that of Bahia occurs along a considerable part of the coast of the state of Alagoas to the northward of the city of Maceio.[1]

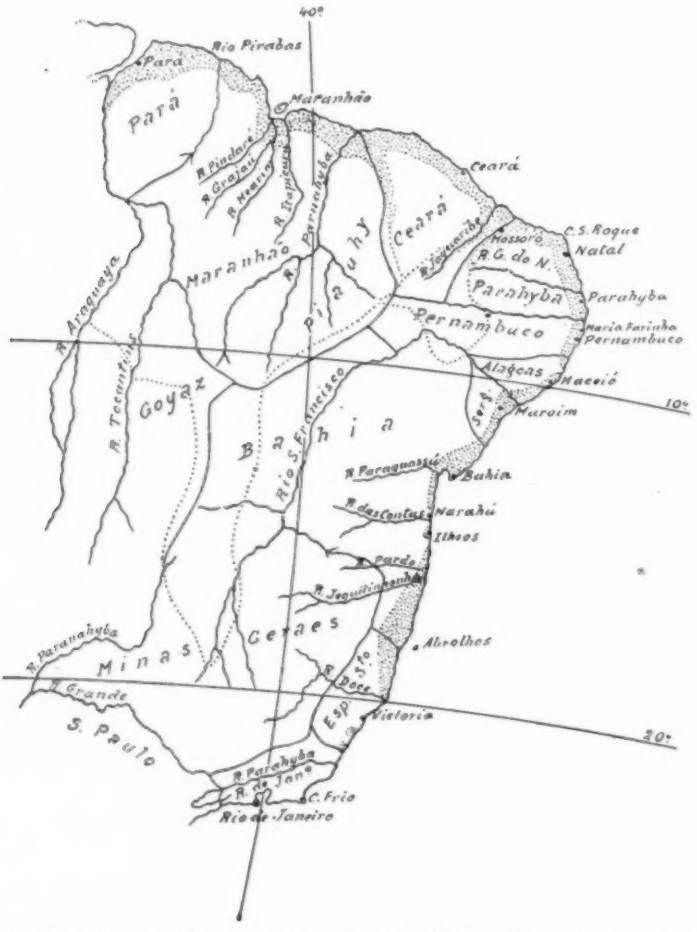
Gonzaga de Campos (**15**) has recently shown that the fresh-water formation of Bahia extends southward along the coast to Marahú, where it is associated with marine beds containing a fauna similar to that of Sergipe, while unpublished observations by Ennes de Souza and the present writer show that another basin of the same character exists farther southward in the neighborhood of Ilheos.

The approximate interior limit of this sedimentary belt in the section from the state of Espirito Santo to Rio Grande do Norte has been given in several recent papers by Branner (**12**, **13**, **14**), but without attempting to discriminate the two members above indicated, which with our present knowledge is indeed an impossible task. The accompanying sketch map is in great part compiled from the various maps accompaning his papers. Throughout the section of the coast here represented to Cape St. Roque the higher lands lying back of the sedimentary belt are composed of very ancient metamorphic rocks, for the most part probably Archean, with their accompanying eruptives, though in a few places (Lower Jequetinhonha and Rio Pardo, Inhambupe near Bahia, and Serra de Itabaiana in Sergipe), unmetamorphosed beds, probably of early or middle Paleozoic age, are known to occur. Farther northward, in the states of Ceará, Piauhy, Maranhão, and Pará, it is probable that they abut against or perhaps merge into, the high-lying beds of presumably Mesozoic age that form the table-topped hills and ridges so characteristic of considerable portions of those states. It is possible also that in the three latter states they will be found in close connection with late Paleozoic (Permo-Carboniferous) strata. Regarding these points, however, nothing is definitely known.

As above stated, the strata of this sedimentary belt fall on the

[1] The origin of the bituminous shale described by M. Bertrand (*Travaux et Mémoires de l'Université de Lille*, VI. Mem. 21, 1898) from Ceará is not certainly known.

most casual inspection (which, except in limited areas, is all that it has yet received) into two distinct divisions, each of which will



doubtless be found susceptible of subdivision. These are: (1) a lower series of sandstones, shales, and limestones, which are in part fossiliferous, and which have been subjected to slight earth-movements, giving the beds a moderate but irregular dip; and (2) an

upper series of soft sandy and clayey sediments that for the most part is without fossils and undisturbed by earth-movements of a character to affect the horizontality of the beds. So far as known to the writer, in no place have these two series been seen in actual juxtaposition, and an unconformability between them is rather assumed than actually proven. In each series there are beds, especially the sandy ones, that closely resemble each other, so that their discrimination is often a matter of doubt.

Following Allport, and Hartt, and the various paleontologists to whom their material was submitted, the lower series has been referred to the Cretaceous and the upper to the Tertiary. This classification has lately been questioned by Branner (**12**, **13**, **14**), who is inclined to refer to the Tertiary much that has hitherto been called Cretaceous. In his recent examination (the most complete and minute that has yet been made) of the coast from Natal, Rio Grande do Norte, to Caravellas in southern Bahia, he found that none of the physical characteristics (lithological character, coloring, inclination of the beds, etc.) can be depended upon for the discrimination of the two series, though he does not put in doubt their actual existence. In examining the paleontological evidence, he finds that unequivocal Cretaceous marine types have been found only in the Sergipe basin and at Parahyba, and that the general aspect of the faunas of the Pernambuco (Maria Farinha, Olinda, and Ponto das Pedras) and Pará basins is decidedly Tertiary rather than Cretaceous, and that the same is the case with the invertebrates of the Bahia fresh-water basin.[1]

These doubts of Dr. Branner are undoubtedly well founded, and in a recent excursion in the region about Bahia and Ilheos I fully sympathized with him in his difficulties in determining the dividing line between the upper and the lower series, and like him I referred to the latter a number of outcrops that formerly I should

[1] In the earlier of his papers embodying this view Branner refers these supposed Tertiary faunas to the Eocene, and quotes Dr. Gilbert D. Harris to the effect that the marine forms are probably not older than the Midway Eocene. In his latest paper (**14**), however, he mentions Cretaceous cephalopods from one of the Pernambuco localities, and quotes a letter from Dr. Smith Woodward to the effect that the vertebrates of the Bahia Basin suggest a doubt as between Jurassic and Cretaceous rather than between Cretaceous and Tertiary.

unhesitatingly have referred to the former. Such perplexities are not unknown in other regions where the difficulties of geological study are far less than in Brazil, and where the number of geological students to set about unraveling them is far greater. They are of great importance when attempts at areal geology are to be made, but for the region in question they may for the present be put aside. The really important questions for the moment are: Is the reputed division into an upper and a lower series a real one; and, if so, what part, if any, of the latter belongs to the Cretaceous?

Dr. Branner apparently does not put in doubt an affirmative answer to the first of these questions, and this, therefore, can be summarily put aside. In regard to the second he expresses serious doubts, which, however, seem to have varied from time to time; and this makes it desirable to discuss the question, locality by locality.

The fossiliferous beds of all the numerous Sergipe localities examined by him are unhesitatingly set down by Branner as Cretaceous, and the overlying non-fossiliferous ones are referred to the Tertiary, apparently on the same stratigraphical and topographical criteria that were used by Hartt and others. Some of the species are admitted by him to present a decidedly Jurassic aspect, and on referring to Dr. White's memoir we find that their number (nine) is somewhat in excess of that (seven) cited from the Pernambuco beds to establish their Tertiary age. Curiously enough, the beds containing the greater number of these species of Jurassic aspect are the same that carry the greater number of the species common to the Pernambuco and Pará beds which Branner would refer to the Tertiary, and the most decided Jurassic form of all (an Ammonite) is from a bed that is referred to the top rather than to the bottom of the series which is given as presenting a considerable vertical range. The most characteristic Cretaceous forms are the Ammonites, represented by fourteen species, of which only three occur in the three localities most abundant in other mollusks. If, therefore, by the chances of collection, only these localities had been examined, and if these few Ammonites had been overlooked, a doubt regarding the Sergipe basin as between Jurassic and Cretaceous might have been raised on the same ground as that raised between Cretaceous and Tertiary for the Pernambuco and Pará basins. Some of the other localities,

however, present a well-characterized Cretaceous fauna, which, as a whole, can be taken as typical of the marine Cretaceous of the Brazilian coast region, although it is to be noted that only five species are positively identified as occurring elsewhere.

In the Pernambuco district the principal locality is Maria Farinha, which has furnished seventy-three species of invertebrate fossils which, in the opinion of a number of prominent European and American paleontologists, present a more decidedly Tertiary than Cretaceous aspect. Of these species two are Echinoids, of which one is referred to a characteristic Cretaceous genus (Toxaster) and the other to a new genus, which is therefore unavailable for correlation. Of the seventy-one mollusks, the single Cephalopod and four of the sixty-eight Gasteropods are referred to species known outside of Brazil. These are: *Nautilus sowerbyanus* d'Orb., *Volutilithes radula* Sow., *Nerinea inaugurata* Stoliczka, *Euspira pagoda* Forbes, and *Turretella elicita* Stoliczka. Branner, on the basis of a study by Dr. Ralph Arnold, questions the identification of the second and fifth of this list, and cites the first two as characteristic Tertiary (*sic*) forms. Even if these doubts be admitted, there would still remain two Cretaceous against two Tertiary forms, whereas White gives four Cretaceous against no Tertiary forms. In any case, the evidence from known species is weak and may very properly be considered as inconclusive for either reference, though note should be taken of the presence of the characteristic Cretaceous genera Toxaster and Nerinea.

The evidence for Cretaceous age to be drawn from a comparison with the Sergipe fauna is somewhat stronger, though still less conclusive than could be desired. Six species, including one of those above mentioned (*Euspira pagoda*), are identified as common to the two regions. When it is considered that the Pernambuco and Pará faunas, whose correlation no one seems inclined to contest, have only twelve (or fifteen including three doubtful forms) species in common, this showing is not so unfavorable as might at first sight appear, and affords at least a stronger presumption in favor of the Cretaceous than any I have yet seen cited in favor of the Tertiary age.[1] This presumption is greatly strengthened by Branner's state-

[1] The list of Tertiary forms presented by Branner in his latest discussion of the subject (*The Stone Reefs of Brazil*, p. 15) includes, besides the two cited above given by

ment that he saw in the possession of a gentleman at Pernambuco specimens of Cephalopods that he calls Cretaceous, from the limestone of the island of Itamarica, close by Maria Farinha, and that he himself collected on the same island one of the most characteristic of the Maria Farinha fossil shells.[1] As no good reason has yet been presented (from my personal knowledge of the district I doubt that any can be presented, for presuming that there are two widely distinct fossiliferous formations in this vicinity, it is reasonable to assume that the lack of strongly characteristic Cretaceous types in the collection submitted to Dr. White for study was due to the chances of collecting, and that, if the island of Itamarica had been thoroughly explored, the general aspect of the Pernambuco fauna would have come out with much greater similarity to that of Sergipe. The other Pernambuco localities, Olinda and Ponta de Pedras, have been shown by Branner to be clearly correlated with that of Maria Farinha, and therefore need not be discussed here.

The Parahyba locality, being set down by Branner as unquestionably Cretaceous, need only be noted as another example of the collector's chance—in this case a particularly happy one, as only three recognizable fossils were obtained. It seems reasonably probable that this and the Pernambuco localities will eventually prove to be remnants of a single original basin.

The Mossoró or Apody basin, in the state of Rio Grande do Norte, is very imperfectly known. My recollection of the impression given several years ago by the casual inspection of fragments of limestone with imperfectly preserved fossils is that the fauna

White as characteristic Cretaceous forms, five others that have not as yet been found in other localities, either in Brazil or elsewhere, and belonging to genera which might be either Cretaceous or Tertiary.

[1] Another fossil from the same locality is referred to a species occurring in the fresh-water beds of Bahia—a rather singular combination, which is repeated at Ponta de Pedras, where this and still another characteristic fresh-water form are reported in association with a well-characterized marine fauna.

With reference to the discovery of Cephalopods (Ammonites ?) in the limestone of Itamarica, it may be remarked that this and Branner's discovery of fossils at Parahyba seem to confirm an instinctive feeling that I have long had, that whereever fossiliferous limestones are found in this sedimentary belt their fauna will be found to present a more characteristic Cretaceous aspect than that of the arenaceous and argillaceous beds. From several chance remarks it seems that Branner had the same impression.

would eventually prove to be similar to that of the Pernambuco beds.

The Pará basin (**9**, **10**) has furnished fifty-two species of mollusks (Lamellibranchs and Gasteropods), and as these were obtained from a few loose blocks picked up at a single point at the mouth of the Rio Pirabas, it is to be presumed that the fauna is a much richer one. Indeed, Kraatz-Koschlau (**16**) states that corals, echinoids, and reptiles also occur, but as yet nothing is known of their character. With one doubtful exception (*Pteria linguiformis* Evans & Shumard), all of these species are as yet unknown outside of this Brazilian coast belt, although six are cited by Ortman (Branner, **14**) as closely resembling Tertiary species from Patagonia. Twelve (or fifteen including three doubtful forms) are identified as occurring also at Maria Farinha, and seven (including two found also in the Pernambuco basin) in Sergipe. The general aspect of the fauna is stated by good authorities to be decidedly Tertiary, but, so far as I can learn, no distinctively Tertiary genera or species have been cited from it, whereas the occurrence of several species that are found also in Sergipe affords a reasonable presumption that, with more extensive collections, characteristic Cretaceous forms are liable to turn up. As already remarked, a chance collection made from certain of the Sergipe localities might readily have been equally equivocal in general aspect, owing to the deficiency of representatives of characteristic Cretaceous genera.

The evidence of a correlation between the Pará and the Pernambuco faunas is somewhat stronger, in a positive sense, than that of the Pará and Sergipe ones, due to the presence of a greater number of species in common; and is decidedly stronger in the absence of characteristic Cretaceous forms. This last argument for a Tertiary age will, however, break down if Branner's casual identification as Cretaceous of the Cephalopods seen at Pernambuco be accepted as final.

One of the most interesting localities of the whole sedimentary belt is that of Marahú, about 60 miles south of the city of Bahia, since here the marine and fresh-water fossiliferous members of the series are found in close juxtaposition. This locality will be discussed below, and only the marine fossils will be mentioned here.

A small collection brought from there by Gonzaga de Campos (**15**) represents an earthy limestone bed and one of calcareous mudstone, both being quite similar in appearance to some of the beds of the Sergipe basin. The limestone has afforded a pectinoid shell apparently identical with *Neithea quadricostata* Sow., which is a very characteristic form of the Sergipe limestone, and a small echinoid. The fossils from the mudstone represent species of *Cucullaea*, *Cardium*, *Corbula*, *Crassatella*, *Isocardia*, and *Tellina*, closely resembling, if not identical with, the representatives of these genera in the beds of similar material of the Sergipe basin. Although no critical comparison of the species could be made, there can be little doubt that the marine beds at Marahú represent substantially the same geological horizon as those about Maroim, in the state of Sergipe.

With regard to the fresh, or rather brackish, water deposits of the neighborhood of Bahia and other parts of the coast belt, Branner's doubts of the correctness of their reference to the Cretaceous seem to have been based, in the first instance, on the modern aspect of the mollusks that occur in them, being afterward somewhat modified, though not entirely withdrawn, by Woodward's statement, above referred to, that the vertebrate fossils are of Mesozoic types. In his latest reference to the subject (**14**) he suggests that possibly the vertebrate and molluscal elements of the fauna may belong to two distinct formations which have not been defined and separated from lack of proper stratigraphical and paleontological work, and notes appearances that suggest an unconformability between beds of two separate ages. Dr. I. C. White, who has also visited the typical locality at Monserrate Point, informs me that he also noted an appearance of unconformability that may possibly explain the apparent disaccord of the two fauna-elements.

In a recent visit to Bahia the typical section was examined with these doubts in mind. The stratification is very confused, layers of conglomerate, sandstone, and shale being mingled in a most perplexing manner and disturbed by a number of minor folds. The molluscan remains occur in thin layers and detached lenses of limestone, and in no case were they found in immediate association with the vertebrate remains. They were, however, found both above and below one of the lines that best simulates an unconformable contact,

and in one lens they were associated with plant remains, in the characteristic form of jet, which is of frequent occurrence in the layers containing fossil vertebrates. In short, the re-examination of the section with this point especially in view convinced me that it represents a geological unit. At the other locality, near Pojuca station, where mollusks occur, Mr. Mawson, a very competent and painstaking observer, reports (**10**) vertebrate and molluscan fossil from the same layer of only a few inches' thickness.

In view of these observations, the hypothesis of an admixture, through careless collecting, of fossils from two distinct formations may be safely put aside, and as the molluscan fauna is a comparatively characterless one, but little weight should be given to it as against the well-characterized Mesozoic forms of the vertebrate fauna.

The strictly fresh-water faunal elements of the Bahia basin are not sufficiently widespread, either in horizontal or vertical range, to characterize the formation as a whole, and it seems probable that, instead of being in a strict sense a fresh-water basin, it was rather an estuary or semi-detached arm of the sea in which deposits characteristic of fresh, brackish, and salt water might be laid down in different parts (or at different epochs in the same parts) and in close connection, or rapid alternation, with each other. A widespread and characteristic feature is the terrestrial elements represented by plant and dinosaurian remains. The former are represented by scattered fragments of carbonized wood, usually in the form of more or less pulverulent lignite in the sandstones and of jet in the shales.

Throughout the district the beds with recognizable fossils are overlain by soft sandstones, which, when they show plant remains or are distinctly inclined, have been referred to the Cretaceous, and in the contrary case to the Tertiary. As Branner has pointed out these criteria are unsafe ones, and doubtless some errors have been committed. My own impression is that in most cases these errors will prove to have been in the sense of placing the limit between Cretaceous and Tertiary too low down, rather than, as Branner seems to think, not low enough. The plant-bearing beds are often horizontal, or apparently so, over considerable areas, and if, as may readily happen, no plant remains are observed in such areas, they may erroneously be referred to the Tertiary. Indeed, it is by no means

certain that a horizontal position, even when general, is a sure index of Tertiary age, although this hypothesis has, for this region, a strong presumption in its favor. Thus far the only known fossils in the beds referred to this age are the leaves of Ouriçanguinhas from the high tableland (400 meters) back of Alagoinhas, which has been referred to the Pliocene (**17**, **18**). As all the species are described as new, it is possible that they may prove to be somewhat older. Between this horizon and that of the fossiliferous beds discussed above there is almost certainly one (and there may be several) geological divisions to be established; but where the dividing line, or lines, between them—that is to say, between some horizon, probably not the extreme upper one, of the Cretaceous and a horizon of the upper Tertiary—is to be drawn must remain a subject for future study. Branner's protest against drawing it at the top of the known fossiliferous beds is a timely one, and his reserve in the matter of indicating another position for it is significative of the difficulties of the subject.

From Bahia southward for a considerable distance along the coast sedimentary beds similar to those about the bay have been reported from a number of points, so that it is tolerably certain that the formation is, or was formerly, continuous from Bahia to the region of Marahú which has recently been examined by Gonzaga de Campos (**15**), and more cursorily by myself. The former reports, in addition to the marine beds already mentioned, a sandstone with carbonized wood which he compares very properly with the similar strata about Bahia. The relative position of the marine and fresh-water beds could not be positively determined, but he was inclined to think that the former overlie the latter. Without being positive on the subject, it seems to me that the contrary will prove to be the case. These beds scarcely rise above tide-level and can be well seen only at extreme low tide, so that a proper examination of their numerous widely separated localities involves many days' labor. The soft parti-colored sandstone most in evidence in the region is apparently without fossils and apparently horizontal, and for these reasons Campos referred it to the Tertiary, and assumed that the "turfa"[1] deposits

[1] The so-called turfa of Marahú is, in part, a peculiar light (sp. gr. 0.92), non-schistose, bituminous substance of earthy aspect and yellow color, containing about 70

that have made the place famous, and that were mainly under water at the time of his visit, also belong to that age. The occurrence of fossil leaves of modern aspect in the turfa seemed to him to confirm this view.

At the time of my visit a boring had been made into the turfa beds and, the pit excavated in them being freed from water, a number of interesting features that escaped Campos' observation could be seen. A gentle flexture has brought above tide-level, at the oil-works, a series of shale beds which are covered by heavy beds of soft sandstone that participated in the flexture. The shales were penetrated by the boring to the depth of about 30 meters, but, as the record was not at hand no accurate account of it can be given. At the top, above the beginning of the boring and immediately underlying the sandstone, is a bed, 4 meters thick, of marahuite containing fossil leaves. The boring penetrated clay shale with intercallations of rich oil-shale for a depth of about 20 meters, then a thin layer of sandstone, and stopped at the top of a second shale bed. As shown by fragments of the core that had been preserved, a lower layer of marahuite was met with somewhere in the midst of the shale series, which also carries fossil leaves, of which a small collection has been forwarded to Dr. David White. Cutting the shale beds and penetrating into the marahuite (where they become diffused as an asphaltic impregnation) are thin (1-2 centimeters) stringers of a coal-like substance which, so far as can be made out, is quite similar to the albertite of Nova Scotia. The marine beds of the district are reported by Campos at a distance of about 2 kilometers to the southward and eastward of this locality, and it seems to me tolerably certain that they underlie the shale beds. This

per cent. of hydrocarbons, 10 per cent. of fixed carbon, and 15–20 per cent. of ash which is peculiar in consisting in great part of alumina soluble in acids. Campos, who has made a careful study of it, showed that it has essentially the composition of the so-called Boghead coals which, as Bertrand has shown, consist of a fundamental yellow base with a secondary infiltration of asphalt. As employed at Marahú, the term also covers a dark-colored shaly material, which is a true oil shale in which the hydrocarbons are of a somewhat different composition and the earthy element of the ash is argillaceous. Both give a high yield of gas and oil, and in the attempts to work the material were used indiscriminately under the general name of turfa. Although the yellow material is perhaps a true boghead, it is sufficiently different from the ordinary type to merit a distinctive name, and it may be called Marahuite.

seems to be confirmed by an observation made by Campos about 8 kilometers to the northward, where he found a shale with carbonized wood overlying the marine limestone and underlying the Tertiary(?) sandstone. All things considered, I have little hesitation in identifying the shale series at Marahú (with the included marahuite) with the Cretaceous series at Bahia, and in including in it a large part, if not all, of the so-called Tertiary sandstone at the former place. It is to be hoped that other borings will soon be made in this interesting locality that will settle these doubtful points.

The metamorphic highlands lying back of the sedimentary belt at Marahú extends down to the coast a few kilometers to the south of the town and abut on the coast for a distance of about a score of kilometers. To the southward the sedimentary belt again appears in the neighborhood of the town of Ilheos. The shales and sandstones composing it closely resemble, both to the north and the south of the town which is on a point of crystalline rocks, those about the bay of Bahia, and this correlation is fully confirmed by a fine collection of fossils made some years ago by my friend Dr. Ennes de Souza, which I lately had an opportunity of examining. The characteristic features of this collection are the fossil ganoid fishes and fragments of jet, both of which are very characteristic of the formation at Bahia. Fortunately, arrangements have about been completed for having this collection studied by a competent paleontologist.

From Ilheos southward to near Victoria, in the state of Espirito Santo, the sedimentary belt is unbroken, except by valleys of denudation, but no outcrops that can be definitely referred to the Cretaceous are known, though it will not be surprising if much of the so-called Tertiary sandstone of this section of the coast should eventually prove to be of that age. In front of the southern portion of this section, at a distance of about 40 miles from the mainland, lie the Abrolhos islands, where Hartt (4) reports fossiliferous limestone, shale and sandstone which he compared with the strata about Bahia. No recognizable fossils were found, but plant impressions and markings resembling scales of teleostean fishes were observed. The beds are somewhat inclined and are overlain by a sheet of basaltic trap. Specimens of this rock collected by Dr. Branner have been examined by Dr. J. P. Iddings, who determined it to be an olivine-gabbro-

diabase. Similar rocks characterize a large region in southern Brazil, where they are presumed to be of Triassic age. As no signs of eruptive activity have been detected in the sedimentary belt of the mainland, it is possible that the Abrolhos outcrop may prove to be somewhat older than those above discussed. However this may be, it must be regarded as a remnant of the same costal sedimentary belt representing a considerable, perhaps the major, portion of it that has disappeared on the submerged border of the continent.

Branner (12) has described several outcrops of oil-shale on the coast of the state of Alagoas, in some of which he found plant remains, and in one a fossil fish identified with a species occurring at Bahia. There can be little doubt that these various deposits are to be correlated with those containing fossil plants and fishes at Bahia, Marahú, and Ilheos. Vague information relating to the northeast section of the coast between Pernambuco and the mouth of the Amazonas indicates that at various points similar deposits occur along it.

The information at present available regarding the unmetamorphosed geological formations of the coast of Brazil may be summarized as follows:

1. With the exception of comparatively rare and short sections, the whole coast from Cape Frio northward is formed, in its highland portions, by Mesozoic and Tertiary sediments, with which are associated eruptives of basic character at the Abrolhos islands.

2. In the southern section of the coast, from Cape Frio to the eastern shoulder of the continent at Cape St. Roque, these sedimentary rocks form only a narrow belt and abut against, or overlap, the margin of a shield-shaped mass of Archean(?) metamorphic and crystalline rocks, fringed in places (rarely along the Atlantic border region) by sharply inclined early Paleozoic strata. In the northern section, from Cape St. Roque northward to the mouth of the Amazonas, they in places extend far inland, occupying baylike indentations in the margin of the Archean (?) shield, or abut against older (?) Mesozoic (Ceará in the semicircle of sedimentary. table-lands—Serras de Apody, Araripe, and Ibiapaba—that surround a minor shield in the central part of that state), or late Paleozoic (Piauhy, Maranhão, Pará, and northern Goyaz) strata that form the high

sedimentary table-lands of the Jaguaribe, São Francisco, Parahyba, coast rivers of Maranhão and Pará, and Araguaya-Tocantins basins.[1]

3. The oldest fossils known from this series present a preponderance of Cretaceous types, but with certain forms that standing alone would be referred to the Jurassic; the newest are of late Tertiary (Pliocene ?) types. The geological range is therefore from early(?) Cretaceous to Pliocene, thus embracing both Mesozoic and Tertiary strata.

4. Certain localities representing strata at or near the base of the series present faunas with a decidedly Tertiary aspect,[2] but with a small number of species that occur also in the typical Cretaceous beds. The geological horizon of the beds at these localities is therefore somewhat doubful, but for the present the preponderance of evidence seems in favor of a Cretaceous age.

5. The typical fossiliferous Cretaceous beds are usually somewhat disturbed, whereas the typical Tertiary ones are undisturbed, except probably by vertical movements; and, in the absence of other evidence, this circumstance has been used as a criterion for discriminating the Mesozoic and Tertiary members of the series, but it is obviously an unsafe one. The assumption that the unconformability that doubtless exists is at the contact of the Cretaceous and Tertiary is a plausible one, but is unproven. The evidence of conformability or unconformability is frequently very obscure, and thus becomes practically valueless in rapid reconnaissance work.

Between the fossiliferous Cretaceous beds at the base of the series and the fossil leaf-bed near the top there is, in the Bahia section,

[1] These indentations are represented schematically by dotted lines on the map on p. 222. Cretaceous fossils are known from these table-lands from southern Ceará, eastern Piauhy, and on the São Francisco below the great bend; and Permo-Carboniferous ones from the interior of Piauhy, and on the Maranhão. The great bay embracing a part of the São Francisco valley follows quite closely a larger and older Eo-Paleozoic one that over a great part of that region occurred between the Archean (?) shield of Bahia and Eastern Minas Geraes, and a second (not entirely detached from the first) in Goyaz.

[2] Compared by Professor G. D. Harris, (14 p. 18) with the fauna of the Eocene beds at Midway, Ala. The resemblance is certainly a striking one, but, as above shown, its significance is greatly weakened by the recent discovery of a typical Cretaceous genus (Ammonites ?) in the immediate vicinity of one of the localities affording this doubtful fauna, and presumably from a bed belonging to the same geological horizon.

a thickness of at least 200 meters (and probably considerable more) of strata that, thus far, have not afforded fossils, except unrecognizable fragments of carbonized wood in their lower part, so that there is no paleontological evidence as to where the division line should be drawn. At about 50 meters below the leaf-bed there is a change in the character of the rock, marked by a water horizon, which apparently indicates a break in the succession; but what its significance may be has not been determined. The beds below this horizon are somewhat more argillaceous than those above, and are more widespread, so that there is here an indication of unconformability by overlap. They are also more widespread than the beds below them that can be definitely assigned to the Cretaceous, but they are so like the upper arenaceous members of the latter series as to be inseparable from them without more study than has yet been given to the subject. These intermediate beds of the Bahia section may be presumed to represent the greater part of the so-called Tertiary of the costal region, and while there is a reasonable presumption that they will prove to belong to the early or middle parts of that age, it cannot be definitely proven that they are not upper Cretaceous.

6. The outlines, so far as they have been determined, of the various fossiliferous deposits of the costal region, and the character of their rocks and fossils, indicate that they were formed in estuaries, or partially closed litoral basins, in which marine, brackish, and freshwater sediments might be laid down simultaneously in different parts; or alternately in the same parts. In view of this circumstance, much detailed study will be required to make out the details of the true succession of the different beds and their respective faunas. In the light of our present knowledge, the *apparent* succession is as follows, in ascending order:

a) A marine group, represented in Sergipe and at Marahú, well characterized by a Cretaceous molluscan fauna which in part shows Jurassic affinities.

b) An estuarine group, represented about Bahia (including Marahú), Ilheos, and the oil-shale localities of Alagoas, with a well-characterized Cretaceous vertebrate fauna, which also in part shows Jurassic affinities, land plants and reptiles, cyprids, and rarely freshwater mollusks.

c) A marine group, represented in Pernambuco, Pará, Parahyba (?), and Rio Grande do Norte (?), with a molluscan fauna showing strong Tertiary affinities, but containing several representatives of the fauna of group No. 1.

Unconformability (?).

d) Soft particolored sandstones and clays without known fossils, that practically cover the whole marine belt from Espirito Santo to Pará.

e) Soft red sandstones with intercallated clay layers containing fossil leaves of Pliocene (?) age, represented in Bahia and Sergipe (?) in a limited area to the northward of the bay of Bahia.

7. To the southward of Cape St. Roque the Cretaceous coast-line was not very different from the present one, but lay in places somewhat farther inland, and in others somewhat farther seaward on the submerged border of the continent.[1] Later (if the Tertiary (?) beds prove to be marine) the coast-line swung considerably farther inland. To the northward of Cape St. Roque the Cretaceous coast-line was much more different from the present one.

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[1] The absence of late Paleozoic and early Mesozoic strata in the coastal region of this section, together with the occurrence of Mesozoic (?) beds at the Abrolhos near the margin of the submerged continental border, suggests the hypothesis that from early Paleozoic to middle or late Mesozoic times the land area extended to near this margin, and that a transgression then occurred which established marine and estuarine conditions over a broad belt of which only remnants now remain.

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REDISTRIBUTION OF ELEMENTS IN THE FORMATION OF SEDIMENTARY ROCKS[1]

WARREN J. MEAD

PROBLEM

Sedimentary rocks are derived from the destruction of older rocks—igneous, crystalline, and sedimentary. The pre-existing sedimentary rocks may themselves have come from still earlier sediments, and these in turn from earlier ones, and so on back, but ultimately their derivation may be traced to the igneous and crystalline rocks, the latter term being used to include schists and gneisses resulting from the metamorphism of the igneous and sedimentary rocks, and others whose origin cannot be determined. Obviously igneous rocks, and the crystalline rocks of the Archean or Basement Complex, whatever their origin, have yielded the materials for all later sediments, some of which have gone through several cycles of erosion and redeposition.

The development of a sedimentary rock from an igneous or crystalline rock involves redistribution of the materials, both minerals and elements. In the process of weathering, certain materials are taken into solution, while others are not. Of the materials not dissolved, some are removed by erosion as finely divided rock particles—mud, silt, and sand. The remainder consists of the partially weathered rock and residual clays which remain *in situ* where erosion lags behind such alteration.

The material transported in a solid state, upon deposition, forms the mechanical sediments of shales, sandstones, etc. Of the material carried in solution, a portion is deposited as cementing and vein-filling materials during the process of transportation. After reaching the sea, a part of the remaining material is precipitated, forming the chemical and organic sediments, the limestones, and other carbonates;

[1] This is the first of a series of articles on metamorphic problems to come from the Metamorphic Laboratory of the University of Wisconsin. The next title will be "The Metamorphic Cycle," by C. K. Leith.

and what is not precipitated remains in solution as part of the mineral matter of the sea.

The following table shows the general plan of redistribution:

TABLE I

GENERAL PLAN OF REDISTRIBUTION

Original Rock	Material removed	Carried as solids	Mechanical sediments (shales, sandstones, etc.)
		Carried in solution	Chemical sediments (limestones, etc.)
			Cementing materials
			Vein-filling materials
			Mineral matter of the sea
	Material remaining	.....	Weathered rock
			Residual clays or earth

Various attempts have been made at quantitative estimates of the redistribution above outlined. Figures for the total thickness and relative amounts of the three classes of sediments have been obtained from actual measurement, but such estimates are confined to the present continental areas, taking no account of suboceanic deposits, and are limited to the comparatively small areas which have been studied by geologists. Several estimates have been made based on the nature and amount of material being carried to the sea by rivers, particularly on the ratio of calcareous to clastic sediments formed.

A few estimates have been made based either in part or entirely on chemical evidence. One of these has been made by Van Hise,[1] who has determined the relative amounts of shale, sandstone, and limestone on the basis of observed thickness, combined with chemical considerations, to be 65 : 30 : 5. Average chemical analyses of the shales, sandstones, and limestones were combined in the ratio of 65 : 30 : 5, respectively, and the resulting combination was found roughly to approximate the composition of the average crystalline rock.

A more recent estimate of the same ratio is one made by Clarke,[2] based on chemical evidence. This estimate is discussed on a later page.

[1] C. R. Van Hise, *A Treatise on Metamorphism*, Monograph No. 47, U. S. Geological Survey, 1904, chap. xi.

[2] F. W. Clarke, "The Statistical Method in Chemical Geology," *Proceedings of the American Philosophical Society*, Vol. XLV (1906), p. 21.

In the present paper the redistribution of the elements of the original crystalline rock will be taken up from a purely chemical standpoint. It will be the purpose to determine in what proportions the various sediments should be combined to yield an average composition most nearly like that of the original rocks from which they were derived, and to point out reasons for discrepancies which may develop.

We may look upon the table given on page 239 as an equation which may be written as follows:

$$\text{Original crystalline rock} + \text{Redistribution agencies} = \begin{cases} \text{Shales} \\ \text{Sandstone} \\ \text{Limestone} \\ \text{Vein-filling materials} \\ \text{Cementing materials} \\ \text{Salts of the sea} \\ \text{Residual matter} \end{cases}$$

If the several end-products making up the right-hand side of the equation could all be taken into account in proportion to their abundance, it is evident that the elements of the original rock would all be accounted for unless some minor factor has been overlooked. Of these end-products fair average chemical analyses are available for shales, sandstone, and limestone, and also for the salts of the sea. Of the vein-filling material very little is known in regard to abundance, and an average chemical analysis is impossible. Better, but still poor, results may be obtained from the residual materials. The cementing material is included in the analyses of the mechanical sediments. The sedimentary rocks form the major part of the mass of the secondary material, the other end-products being only a small percentage of the total mass; hence the proper combination of their analyses should approximate the original rocks—i. e., the left-hand side of the equation—even if the less important end-products be not counted, though their omission will cause certain discrepancies. Thus we may expect to find a deficiency of iron, owing to its segregation in iron formations and iron-ore deposits, which are not included in the analyses of the sediments. We may expect to find a deficiency of sodium, owing to the large amount of that element in solution in the sea.

Our purpose, then, is to ascertain in what proportions the sandstones, shales, and limestones should be combined to give the best

approximation to the average composition of the original igneous and crystalline rocks, making due allowances for the end-products other than sediments, not included in the combination.

DATA USED

There are only eight of the elements—oxygen, silicon, aluminum, iron, calcium, magnesium, sodium, and potassium—which compose more than 1 per cent. of the outer part of the lithosphere. The least plentiful of these, potassium, makes up about 2.3 per cent. of the lithosphere, while the next element in abundance, titanium, makes up only 0.4 per cent. The present discussion will be confined to the eight most abundant elements, which will be treated in the form of the following oxides: silica, alumina, magnesia, soda, and potassa. Iron will be considered in the metallic form, the sum of the metallic content of the ferrous and ferric oxides being taken in each analysis employed.

Perhaps the best determination of the average crystalline and igneous rocks yet available is one made by Clarke.[1] In obtaining this average the rock-forming elements were considered separately, each being averaged according to the actual number of determinations made. A group of truer estimates was thus secured than by averaging complete analyses together, as he had heretofore done. In the same bulletin (p. 21) are average analyses of the several sedimentary rocks. The average analysis of the shales represents an average of seventy-eight rocks carefully selected and weighted. Two determinations of the average composition of the sandstones are given. The average represents a composite analysis of 624 sandstones, equal weights being taken. For the average limestone Clarke gives two determinations—one a composite analysis of 345 limestones and the other a composite analysis of 498 limestones used for building purposes. For the present purpose an average of the two composite analyses was taken, representing an average of 834 limestones. The several analyses selected are given in Table II.

Most of the mass of the sedimentary rocks is derived from the crystalline rocks, but, in the process of redistribution, water and gases from the hydrosphere and atmosphere combine with the

[1] F. W. Clarke, *Bulletin No.* 228, U. S. Geological Survey, 1904, p. 17.

"derived" elements, either chemically or mechanically, and thus enter into the constitution of the sediments. These elements *not* derived from the crystalline rocks must be omitted from the analyses of the sediments before any quantitative estimates can be made on the redistribution of the elements of the crystalline rocks. In Table II the "underived" elements are marked with an asterisk, and the sum of the "derived" elements is given below. Omitting the "underived" elements, the analyses are recalculated on a basis of 100 per cent. totals which gives the analyses in Table III.

TABLE II

AVERAGE ANALYSES SELECTED FOR USE IN THE PRESENT DISCUSSION

	Av. Crystalline	Av. Shales	Av. Sandstone	Av. Limestone
SiO_2	60.48	58.38	81.76	9.64
Al_2O_3	15.17	15.47	5.37	1.28
Fe_2O_3	2.61	4.03	1.23	0.65
FeO	3.44	2.46	0.57	....
MgO	4.10	2.45	0.85	6.20
CaO	4.84	3.12	3.28	41.60
Na_2O	3.43	1.31	0.61	0.33
K_2O	2.96	3.25	1.24	0.45
*H_2O	1.89	5.02	1.69	0.97
TiO_2	0.72	0.65	0.33	0.07
P_2O_5	0.26	0.17	0.07	0.23
*CO_2	....	2.64	3.02	35.58
*S, SO, C	....	1.46	0.08	0.15
BaO and MnO	0.10	0.05	....	0.04
Total	100.00	100.46	100.10	100.19
"Derived"	98.11	91.34	95.30	60.49
"Underived"	1.89	9.12	4.80	39.70

TABLE III

"DERIVED" ELEMENTS OF TABLE II RECALCULATED TO 100 PER CENT. TOTALS

	Av. Crystalline Rock	Av. Shales	Av. Sandstone	Av. Limestone
SiO_2	61.60	63.90	85.72	15.94
Al_2O_3	15.47	16.96	5.63	2.12
Fe_2O_3	2.66	4.41	1.29	1.07
FeO	3.51	2.70	0.60	....
Fe	4.60	5.19	1.37	0.75
MgO	4.18	2.69	0.89	10.25
CaO	4.93	3.42	3.45	68.75
Na_2O	3.50	1.44	0.64	0.55
K_2O	3.02	3.56	1.29	0.74

METHODS USED

The problem now is to determine in what proportions the foregoing analyses of shales, sandstone, and limestone (Table III) should be combined so as to give an average analysis as nearly like that of the average crystalline rock as possible. "Cut and try" methods

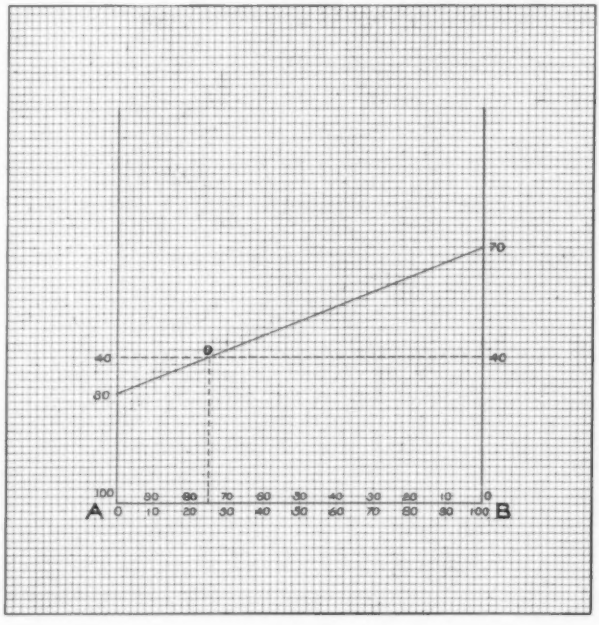


FIG. 1

are both tedious and unsatisfactory. A method of solution has been devised by means of which definite results may be obtained and the general conditions of the problem observed in perspective.

It will perhaps make an explanation of the method of solution clearer if the general principles are first applied to the simpler case of a combination of two analyses. Suppose, for example, it is desired to find out what proportions must be taken of two rocks, *A* and *B*, having respectively 30 and 70 per cent. of silica, to yield a combination that shall contain 40 per cent. of silica. Vertical distances in

Fig. 1 represent percentages of silica, and the two amounts of silica are plotted on the two vertical lines marked *A* and *B*, and the points connected by a straight line. This line represents by its ordinates the amount of silica in any possible combination of the two rocks, from 100 per cent. of one at one end to 100 per cent. of the other at the opposite end. To find what point on the line represents a combination containing 40 per cent. of silica, a horizontal line is drawn at a distance of 40 units from the base. Now, if the point *O*, at the intersection of the two lines, be projected vertically downward to the base, the percentages of the two rocks in the combination may be read at once; the figures above the base line representing percentages of A and those below the line percentages of *B*. It is seen that the combination is made up of 25 parts of *B* and 75 parts of *A*. In a similar manner it is possible to deal with each element in the rocks.

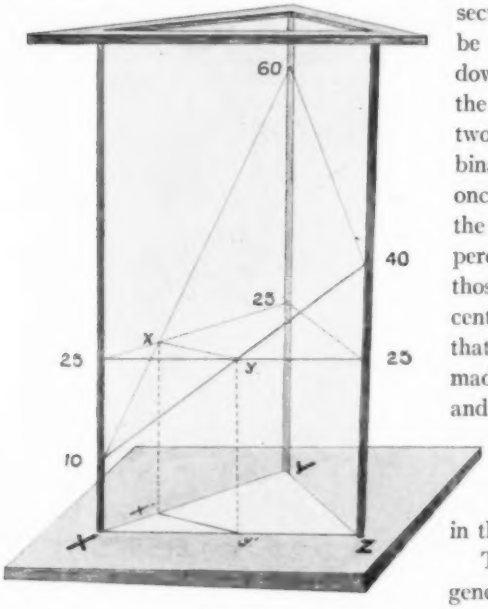


FIG. 2

To apply the same general principle to the case of the combination of three rocks: Suppose, for example, it is desired to ascertain what combination of three rocks, *X*, *Y*, and *Z*, having respectively 10, 60, and 40 per cent. silica, will contain 25 per cent. of silica. It is apparent at once that this problem cannot be considered in two dimensions, as was done in the case of a combination of two rocks; but the same general method may be employed by considering the problem in three dimensions. In Fig. 3 the three uprights are erected perpendicular to the base at the corners of an equilateral triangle. The

uprights correspond to the three rocks, X, Y, and Z, and are lettered accordingly. Vertical distances represent percentages of the elements as in Fig. 1. Points on the uprights representing percentages of silica are connected by a plane, instead of a line as was done in the case of the combination of two rocks. The ordinates of this plane represent any percentages of silica which may result from any possible combination of the three rocks. To ascertain what points in the

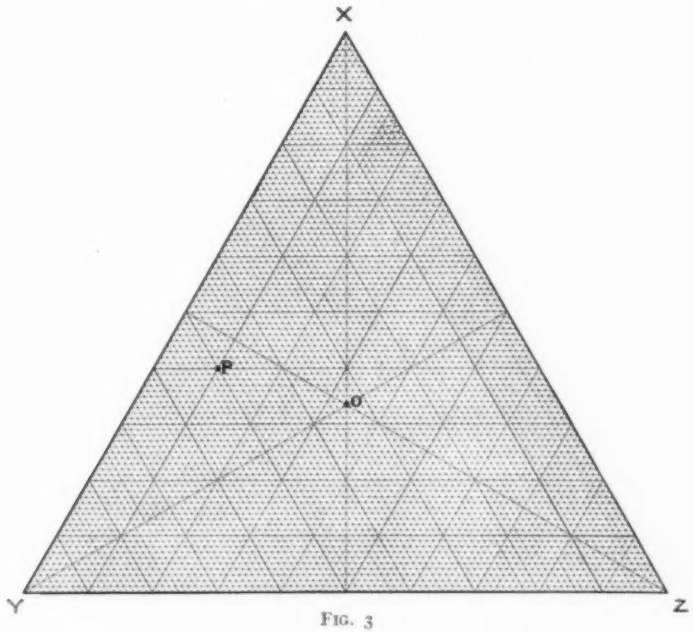


FIG. 3

plane represent 25 per cent. of silica, a plane is passed parallel to the base at a height of 25 units, and the line of intersection of the two planes contains all the points in the first plane which represent the desired 25 per cent. of silica. In the case of a combination of two rocks, as illustrated in Fig. 1, the ratios in which the two rocks entered into the desired combination was determined by projecting the point of intersection of the two lines onto the line at the base. In the case of a combination of three rocks, we have a trian-

gular surface at the base instead of a line. For this triangular surface a piece of triangular cross-section paper is used, like the one shown in Fig. 3. The three corners represent respectively 100 per cent. of X, 100 per cent. of Y, and 100 per cent. of Z. Any point in the triangle represents some combination of X, Y, and Z, and the percentage of each in the combination is measured by the distance

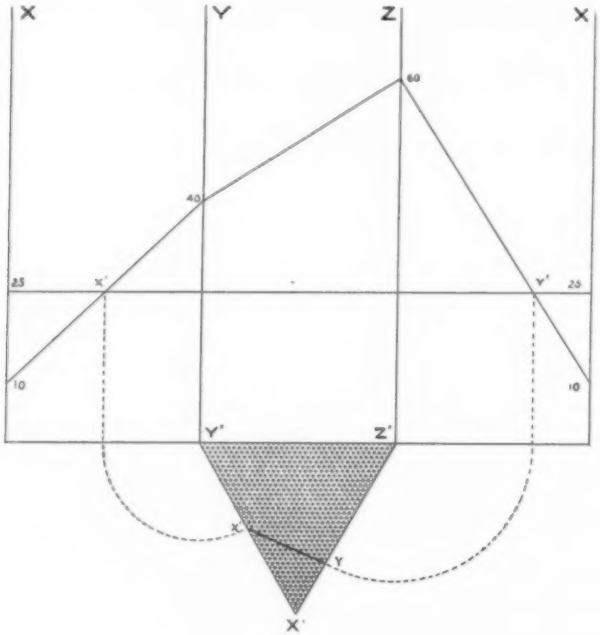


FIG. 4

between the point and the side opposite. To illustrate: the point P represents a combination made up of 40 per cent. X, 50 per cent. Y, and 10 per cent. Z. The point O in the center of the triangle represents a combination containing $33\frac{1}{3}$ per cent. of each of the three.

If the line of intersection of the two planes in Fig. 2 be projected vertically downward onto the base, it will represent all possible combinations of X, Y, and Z which contain 25 per cent. silica. By the same process the planes for the alumina content of the rocks may

be drawn and the line of intersection projected onto the base. This line will indicate all combinations of the three rocks which contain a certain percentage of alumina. The point of intersection of the silica line and the alumina line on the cross-section paper at the base indicates what combination of the three rocks contains the same amounts of silica and alumina as a given fourth rock. That is, we

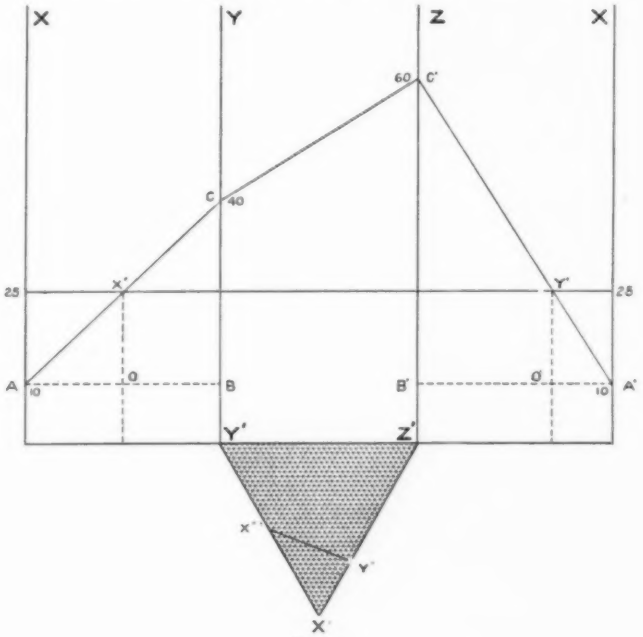


FIG. 5

have found out in what ratios X, Y, and Z must be taken to give a combination having the same content of silica and alumina as a given fourth rock. In the same manner this process may be continued to include the other rock-making elements, and, if the lines on the cross-section paper do not intersect at a common point, it is possible by inspection to determine the point which comes nearest to all of the lines, and thus we may determine what proportions of X, Y, and Z will make a combination which is as nearly like that of

a fourth rock as possible. An apparatus was constructed embodying the ideas shown in Fig. 2 and used in the solution of the problem. Silk threads were used for the edges and intersections of the planes, and to avoid confusion a different color was used for each component.

It was found, however, that more accurate results could be obtained by the following application of the principles involved in the apparatus. The three vertical planes are opened out flat, as shown in Fig. 4. The percentages are plotted as before, and intersections found at X' and Y' and projected down upon the base-line. The distances XY, YZ, and ZX correspond to the sides of the triangle, so the location of the points x and y is an easy matter. The problem admits of easy solution by this graphical method, but a very simple arithmetical solution is also possible which does away with the rather cumbersome details of a graphical solution and also admits of greater accuracy. In Fig. 5 the lines AB and $A'B'$ are drawn parallel to the base. In the left-hand side of the figure we have two similar triangles, ABC and AOx'. Hence $CB : AB :: x'O : AO$.

$$CB = 40 - 10 = 30, \qquad x'O = 25 - 10 = 15,$$

AB is equal in length to the sides of the triangle which is divided into 100 divisions, hence $AB = 100$.

Substituting the values in the above proportion, we have,

$$30 : 100 :: 15 : AO.$$

From which, $AO = 50$, and we see that the point x'' falls on the side $X'Y'$ of the triangle at a distance of 50 units from X'.

Considering the right-hand side of the figure, we have as before two similar triangles, $C'B'A'$ and $y'O'A'$, and we may write the following proportion,

$$C'B' : B'A' :: y'O' : O'A',$$

$$C'B' = 60 - 10 = 50, \qquad y'O' = 25 - 10 = 15, \qquad B'A' = 100,$$

substituting values in the above proportion,

$$50 : 100 :: 15 : O'A',$$

solving,

$$O'A' = 30.$$

We find that the point y'' falls on the side $X'Z'$ of the triangle at a distance of 30 units from X'.

RESULTS

The method of solution here described was applied to the four average analyses given in Table III, and the triangular diagram thus obtained is shown in Fig. 6. Since all the lines of the several elements in Fig. 6 do not intersect at a common point, some point must be selected which will give a minimum of discrepancies when the combination of the sediments is compared with the composition

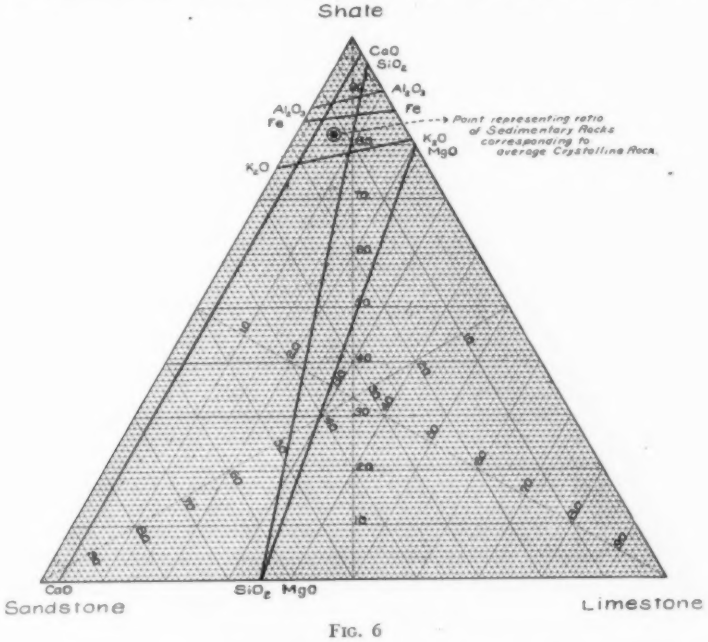


FIG. 6

of the average crystalline rock. A rough idea of what these ratios are may be obtained from a general inspection of the diagram, and it is seen at once that a point as near to all of the lines as possible lies near the "Shale" corner of the triangle and a little to the left, indicating a large predominance of shale and more sandstone than limestone. The two elements which have the greatest bearing on the selection of the best ratio are calcium and silicon, since these two elements are more unevenly distributed among the three sedi-

ments than any of the others, and any deviation from the best ratio will consequently produce greater discrepancies in calcium and silicon than in the elements which are more evenly distributed among the three sedimentary rocks. For this reason it is probable that the best point lies somewhere between the lime and silica lines. By referring to Table III it is seen that the shales contain more iron than either of the other classes of sediments, and hence a point above the iron line would indicate an excess of iron in the sediments and a point below it a deficiency. As we know that iron is segregated to a large extent in iron formations and ores, a deficiency is more probable than an excess, and the point evidently lies below the iron line. This throws it inside of the area bounded by the calcium, silica, iron, and potassa lines. A point at the center of this area gives a ratio of 82 parts shale, 12 parts sandstone, and 6 parts limestone, considering only such a part of the masses as is made up of the "derived" elements.

From Table II it is seen that the "derived" elements of the shales make up only 91.34 per cent. of the mass, of the sandstone only 95.30 per cent., and of limestone only 60.49 per cent. It is evident, then, that in the above ratio 82 represents only 91.34 per cent. of the total mass of the shales, 12 represents only 95.30 per cent. of the total mass of the sandstone, and 6 represents only 60.49 per cent. of the total mass of the limestone. If these figures are recalculated to take into account the entire mass of the sediments, we have as a ratio of shales, sandstone, and limestone, in even numbers, 80:11:9, respectively.

The relative abundance, then, of the three classes of sediments, as determined in the present investigation on the basis of average composition of crystalline rocks, is 80 parts shale, 11 parts sandstone, and 9 parts limestone.

The same process of solution was applied to a series of five average analyses of crystalline rocks,[1] ranging from acid to basic, and the same predominance of shale was observed in each case, ranging from 79 per cent. for acid rocks to 88 per cent. for the basic end of the series. This would seem to indicate that the redistribution of any crystalline rock results in a large predominance of shale in the

[1] Wright, *Tables of Igneous Rocks*, after Rosenbusch's classification.

resulting end-products. As would be expected, the ratio obtained from the average crystalline rock lies between those obtained for acid and for basic rocks; but it is noticed that the intermediate figure, 80 per cent., lies nearer the percentage of shale derived from acid rocks, 79 per cent., than that derived from basic rocks, 88 per cent. This indicates that in the group of analyses from which Clarke's average crystalline rock was obtained there was a considerable predominance of acid rock over basic rocks. This is in accord with the general opinion as to their relative importance.

DISCREPANCIES

In the following table the analyses of shales, sandstone, and limestone given in Table III have been combined in the ratios of 82:12:6, respectively, derived elements only being considered, and the resulting combination compared with the average crystalline rock.

TABLE IV

	Composition of Average Crystalline Rock	Average Analyses of Shales, Sandstone, and Limestone combined in the ratios of 82:12:6 respectively	Differences between the Composition of Av. Crystalline Rock and Comb. of Sediments
SiO_2	61.60	63.64	+2.04
Al_2O_3	15.47	14.71	−0.76
Fe	4.60	4.46	−0.13
MgO	4.18	2.90	−1.28
CaO	4.93	7.34	+2.41
Na_2O	3.50	1.29	−2.21
K_2O	3.02	3.12	+0.10

In the right-hand column the plus signs indicate an excess of that element in the sediments, and a minus sign indicates a deficiency.

While the sedimentary rocks form a very large proportion of the end-products of redistribution, it is evident that in considering only the sediments, as has been done in the solution of this problem, certain discrepancies may arise owing to the omission of the other end-products. These omitted end-products may account to a considerable extent for the discrepancies in Table IV. The most important of these omitted factors which admit at all of quantitative consideration are: mineral matter of the sea, the iron formations, and the residuary matter of the land. With a view of ascertaining to what extent the omission of these factors is responsible for the discrepancies

obtained, certain suppositions have been made regarding the composition and abundance, based on the best evidence at hand. Van Hise[1] estimates the average thickness of the sediments over the continental areas as 2 kilometers, or about 6,000 feet, and their total mass as 675,000,000,000,000,000 metric tons. This estimate is well in accord with Salisbury's[2] estimate of one mile for the thickness of the sediments. The salts of the sea, computed as oxides from Dittmar's determination, amount to a total mass equal to about 3.5 per cent. of the total mass of the sediments, as estimated by Van Hise. It is assumed that the average thickness of the residual mantle over the continental areas is 60 feet, or 1 per cent. of the total thickness of the sediments, and as a rough approximation the thickness of the iron formations, if spread uniformly over the continents, is 60 feet, or 1 per cent. For the chemical composition of the residual material an average was taken of several analyses of residuary materials given by Merrill.[3] For the average composition of the iron formations an average was taken of several hundred analyses of Lake Superior iron formations, weighting the ratio of iron-carbonate to iron-silicate rocks in the proportion of seven of the former to three of the latter. It is not assumed that the figures for composition and abundance here employed represent very closely the facts, but they are sufficient to show, in a rather broad way, the effect which a consideration of these minor end-products would have on the discrepancies arising.

TABLE V

	Comp. of Sediments 82:12:6 100%	Mineral Matter of the Sea. Calculated 3.5% of Sediments	Av. Comp. of Residual Material. Assumed 1% of Sediments	Av. Comp. of Iron Formations. Assumed 1% of Sediments
SiO_2	63.64	00.00	61.45	51.40
Al_2O_3	14.71	00.00	21.94	1.25
Fe	4.46	00.00	8.25	28.50
MgO	2.90	12.31	0.99	5.38
CaO	7.34	3.32	0.98	3.82
Na_2O	1.29	81.76	0.81	0.00
K_2O	3.12	2.64	1.84	0.00

[1] C. R. Van Hise, *A Treatise on Metamorphism*, Monograph No. 47, U. S. Geological Survey, 1904, p. 940.

[2] R. D. Salisbury, "Mineral Matter of the Sea," *Journal of Geology*, Vol. XIII, September-October, 1905.

[3] G. P. Merrill, *Rocks, Rock-Weathering, and Soils*, p. 306.

In the foregoing table are given the compositions of the end-products of redistribution and their relative abundance.

In order to find the composition of the sum of the end-products, it is necessary to combine the above analyses in the ratios of abundance. In Table VI the result of this calculation is given and compared with the composition of the average crystalline rock.

TABLE VI

	Composition of Average Crystalline Rock	Comp. of Sediments 82:12:6	Diff.	Comp. of Combined End-Products	Diff.
SiO_2	61.60	63.64	+2.04	61.39	−0.21
Al_2O_3	15.47	14.71	−0.76	14.16	−1.31
Fe	4.60	4.46	−0.13	4.58	−0.02
MgO	4.18	2.90	−1.28	3.21	−0.97
CaO	4.93	7.34	+2.41	7.11	+2.18
Na_2O	3.50	1.29	−2.21	3.99	+0.49
K_2O	3.02	3.12	+0.10	3.06	+0.04

By comparing the two columns of differences in Table VI, it is seen that the sum of the differences arising when only the sedimentary rocks are considered is reduced by more than half by including the other end-products in the combination. The discrepancy for each of the elements except one is made considerably smaller. In the case of alumina the difference is increased from 0.76 to 1.31, but for each of the other components the differences are decreased. This very evident improvement in discrepancies would seem strongly to indicate that the discrepancies are to a large extent due to not including in the consideration of the problem all of the end-products of redistribution. It is not improbable that with better figures for average composition and abundance the differences would be reduced still more.

The close accordance between the composition of the combination of sedimentaries and the original crystalline rock, and the relatively small corrections produced by taking into account the other end-products, argues the probable correctness of the ratios determined, and also shows the relative unimportance of the minor end-products of redistribution.

COMPARISON WITH OTHER ESTIMATES

Van Hise estimated the relative abundance of the three sedimentaries as 65 parts shale, 30 parts sandstone, and 5 parts limestone.

In the following table are listed the discrepancies arising under Van Hise's ratio of 65:30:5 and the differences encountered in the present investigation.

TABLE VII

COMPARISON OF THE TWO RATIOS

	Diff. under Ratio of 65:30:5	Diff. under Ratio of 80:11:9
SiO_2	+3.2470	+2.04
Al_2O_3	−3.6800	−0.76
Fe	−1.1490	−0.13
CaO	(no discrepancy)	+2.41
MgO	−2.2025	−1.28
Na_2O	−2.4985	−2.21
K_2O	−0.2925	+0.10

The differences are less for the ratio of 80:11:9 than for 65:30:5. Van Hise's choice of ratio was influenced by estimates of observed thickness and relative proportions, and not alone by analyses.

Another estimate of the relative importance of the three classes of sedimentary rocks is one made by Clarke.[1] In attempting to ascertain the average composition of the lithosphere, he estimates it to be made up of 95 per cent. of igneous rock, with 5 per cent. of sediments, and he assigns 4.0 per cent. to be shales, 0.75 per cent. to the sandstones, and 0.25 per cent. to the limestones. This is equivalent to a ratio of shales to sandstone to limestone of 80:15:5, which accords rather well with the results of the present discussion. Clarke obtained his results by assigning all the free quartz of the average crystalline rock to the production of sandstone and half of the calcium of the average crystalline rock to the formation of limestone. The figure for free quartz was obtained from petrographical descriptions of about 700 igneous rocks.

The results of the present investigation are also roughly in accord with the results obtained from measurement of materials carried by rivers, but so many factors enter into such comparison that it will not be discussed here.

It is hardly to be expected that the relative abundance of the principal sedimentaries determined from field observations should

[1] F. W. Clarke, "The Statistical Method in Chemical Geology," *Proceedings of the American Philosophical Society*, Vol. XLV (1906), p. 21.

be in accord with the results obtained in the present investigation, which are based entirely on chemical evidence. This lack of accordance should not be interpreted as evidence that either of the ratios is incorrect. The figures obtained from field observations take into consideration only the present continental areas, and if it is assumed that they correctly represent the results of redistribution, it is also necessary to assume that the sedimentary formations at present on the continental areas constitute practically all of the redistributed material, or that sedimentation has been uniform over the earth's entire surface, in which case an average geological column for the continents would represent average sedimentation. The ratio based entirely on chemical evidence is not necessarily limited by the assumptions above mentioned, and for this reason it is believed that 80 per cent. shale, 11 per cent. sandstone, and 9 per cent. limestone is a better measure of the net results of redistribution than figures based on field evidence alone.

SUMMARY AND CONCLUSIONS

The sedimentary rocks are ultimately derived from the igneous and crystalline rocks. The general average composition of the sedimentary rocks should equal the average composition of the igneous and crystalline rocks, when minor corrections are made for the materials not classed as sediments, but derived from the same source, such as the salts of the ocean and ore deposits. The three main classes of sediments constitute fully 97 per cent. of the end-products of the destruction of the igneous and crystalline rocks. It should be possible to combine these three great groups in such a manner as to make them yield an average composition similar to that of the parent rock.

It has been the purpose of this investigation to determine the proportion which most nearly accomplishes this result. A quantitative method of solution has been devised which permits of ready and accurate solution of the problem.

The result has been found to be 80 per cent. of shales, 11 per cent. of sandstones, and 9 per cent. of limestones.

This proportion accords with that derived from other methods of

investigation in showing the striking dominance of shales in the sedimentary rocks.

The best available average analyses may not be correct, but the probable error, determined by noting the variations in the data available, is not so wide as to materially affect the result. It is believed that the proportion thus determined is entitled to more consideration than a proportion determined by measurement of field sections or of materials transported by rivers. If this proportion be not essentially correct, the best available average compositions vary essentially from the truth.

The small discrepancies between the composition of the parent rocks and the resultant principal groups of sedimentary rocks are found to be still further reduced when the relatively minute amounts of the minor end-products of the destruction of the parent rocks are taken into consideration.

The proportion of limestone determined (9 per cent. of the principal sedimentary rocks) is smaller than that obtained by measurement of geological sections. If the apparent difference is a real one—in other words, if the data which have entered into the two methods of calculation are reasonably correct—it may be concluded that there has been a concentration of limestone in the continental area. Whether this concentration is simply one of present areal distribution, the fragmental equivalents of the limestone at the present time being largely under the oceanic area, or whether the limestone has been uniformly concentrated through geological time in the upper part of the lithosphere, as has been held by certain writers, remains to be proved.

The work here outlined has been done in the metamorphic laboratory of the University of Wisconsin. I am greatly indebted to Dr. C. K. Leith for direction and criticism.

THE FORMATION OF LEUCITE IN IGNEOUS ROCKS

HENRY S. WASHINGTON

INTRODUCTION

In the following pages are presented the results of an attempt at the determination of the chemical characters of magmas which may control the formation of leucite in igneous rocks. Connected with this is an examination of the validity of the orders of affinity of the bases for silica and for alumina, which have been assumed as fundamental in the calculation of the norm in the quantitative classification. The paper is an extension of some previous studies, to be referred to subsequently, undertaken under the auspices of the Carnegie Institution. It may be pointed out here that the methods employed in the case of leucite are capable of application to other minerals.

I must express my deep obligations to my friends, Dr. Cross and Professor Iddings, with whom the first draft of this paper was discussed, for valuable suggestions in regard to the plotting of the diagrams and other matters, by which the work has gained much in simplicity and, it is to be hoped, in intelligibility.

It is commonly assumed or explicitly stated that the rocks in which leucite occurs are usually low in silica and high in alkalies, especially potash. But no definite limits for silica or for potash have been established, and leucite-bearing rocks are known which are quite high in silica and low in potash. Over forty years ago Roth[1] pointed out that the silica percentage of the rock could be either above or below that of leucite. Roth, in the last-cited work, and subsequently Zirkel,[2] observe that quartz does not occur with leucite, and the latter speaks of this as one of the few laws which can as yet be enunciated in regard to the mineral associations in igneous

[1] J. Roth, *Zeitschrift der deutschen geologischen Gesellschaft*, Vol. XVI (1864), p. 690; and also *Beiträge zur Petrographie der plutonischen Gesteine* (1869), p. 90.

[2] F. Zirkel, *Lehrbuch* (1893), Vol. I, p. 646.

rocks. He also notes the fact that leucite occurs more often in association with plagioclase than with orthoclase.

The characteristic occurrence of leucite in effusive rocks, and its absence from intrusive ones, have long been known, though recent observations have shown some undoubted exceptions to this latter statement. This general association is commonly attributed to the greater pressure under which the intrusive rocks have consolidated, and also in part to the presence of mineralizers, under which conditions leucite does not seem to be stable.[1] The possibility of potash entering the biotite molecule in combination with magnesia and ferrous oxide under certain circumstances, while under others this complex molecule does not form, but its constituents crystallize as leucite and olivine, has been pointed out and discussed by Lemberg,[2] Bäckström,[3] and others.

The general relations between the occurrence of leucite and the chemical characters of the rocks have been discussed by the authors mentioned above, as well as by others, among whom may be mentioned Iddings[4] and Lacroix.[5] These earlier discussions were largely qualitative, but in a more recent paper[6] Iddings discusses the chemico-mineral relationships of rocks from a mathematical standpoint, illustrated by diagrams, and much of the subsequent discussion is closely analogous to his. In these papers of Iddings the theoretical limits of some ideal magmas are pointed out, and the relationships of actual rocks to them are considered. Still more recently[7] Michel Lévy discusses mathematically the limits of the various magmatic divisions of the quantitative classification, with application to certain rocks, but without discussion of leucite.

[1] Cf. J. Lemberg, *Zeitschrift der deutschen geologischen Gesellschaft*, Vol. XL (1888), p. 635.

[2] J. Lemberg, *loc. cit.*, p. 636.

[3] H. Bäckström, *Geologiska Föreningens Förhandlingar*, Vol. XVIII (1896) p. 155.

[4] J. P. Iddings, *Bulletin of the Philosophical Society of Washington*, Vol. XII (1892), pp. 166, 176.

[5] A. Lacroix, *Enclaves des roches* (Macon, 1893), p. 637.

[6] J. P. Iddings, *Journal of Geology*, Vol. VI (1898), p. 219.

[7] Michel Lévy, *Bulletin de la Carte géologique de la France*, No. 92 (1903).

In a paper on the rocks of the central Italian volcanoes[1] the relationships of the leucitic and non-leucitic rocks, and the chemical characters of their respective magmas, were discussed with the view of throwing light on the chemical characters which controlled the formation of leucite in this region. Some general conclusions were reached, which will be referred to subsequently, and some of which seem to be of wider applicability. The present paper, as was mentioned above, is an extension of this study, the field being enlarged to include all known leucitic rocks. The theoretical limitations of leucitic norms are first determined mathematically on the basis of certain assumptions, and these are afterward compared with the actual facts as revealed by a study of the rocks themselves.

A great deal of work has been done in recent years by Morozewicz, Vogt, Doelter and his pupils, Day and Allen, and others, in determining the physico-chemical conditions involved in the formation of many of the rock minerals. While this work is of great value and importance, and highly suggestive in many ways, little reference will be made to it in the present paper, in which the more essentially chemical factors will be the main subject of investigation. This is partly because such an extension of the scope of our inquiry would unduly lengthen the paper, and partly because it is felt that such physico-chemical investigations, are not yet so complete and so detailed, especially as regards leucite, as to make their introduction, and the conclusions to be derived from them, satisfactory. They may and will be invoked in the future for the explanation of many of the facts set forth in the subsequent pages, but such an application here seems to be unjustified and rendered merely tentative by the paucity of our knowledge at the present time.

THEORETICAL DISCUSSION

While it is now well recognized that a given magma solidifying under different physical conditions may form very diverse mineral combinations, within the limits imposed by the chemical composition, yet for any given set of physical conditions it would seem that the relative affinities of the chemical constituents of the magma for

[1] H. S. Washington, "The Roman Comagmatic Region," *Carnegie Publication* No. 57 (1906), p. 181.

each other should determine the minerals actually formed. In accordance with the general facts of chemistry these relative affinities would vary more or less with differences in the physical conditions, such as temperature and pressure, and their influence may conceivably be altered by such factors as mass-action or the presence of catalyzers, bringing about different reactions between the constituents of the magma and the consequent formation of different minerals. But for igneous magmas in general, and within the comparatively narrow range of temperatures between the points where crystallization begins and the mass becomes solid, it will be permissible to assume certain general orders of affinity which should control in the great majority of cases, at least, and which a study of the minerals formed in holocrystalline igneous rocks would reveal to us.

Leaving out of account all of the (usually) minor chemical constituents, for the sake of simplifying the discussion, we may assume that rock magmas are composed of the oxides: silica, alumina, ferric oxide, ferrous oxide, magnesia, lime, soda, and potash. Whether these exist as such in the magma before solidification, or whether they are combined into more complex molecules, is an unsettled question, and one which need not concern us here. It is evident that a study of the relative affinities of each of these for the others would be very complex, but our knowledge of igneous rocks and of their component minerals clearly indicates that certain ones are of especial importance.

Of these the most important, and the one which most interests us, is that of the bases for silica, as silica is always present in the largest amount, and the great majority and the most abundant of the igneous rock minerals are silicates. While no universally applicable order of affinity can be established, for reasons given above, yet the well-known facts of mineralogy and the experimental researches of Lagorio, Morozewicz, and others, indicate the following as being the one which controls in the great majority of cases,[1] and the one which we may assume as fundamental in the present investigation. Beginning with the oxide which has the greatest affinity for

[1] Cf. Cross, Iddings, Pirsson, and Washington, *Quantitative Classification of Igneous Rocks* (Chicago, 1903), p. 192.

silica, this order is: potash, soda, lime, magnesia, and ferrous oxide. A second order of affinity of almost equal importance is that of the bases for alumina, usually the next most abundant constituent after silica. This order is the same as that for silica. Upon these are based very largely the calculation of the norm in the quantitative system of classification, that is, the simplest expression of the mineral molecules which experience has shown are most likely to be formed in igneous rocks.

On these assumptions the most important mineral molecules formed in the norm by each of the above five oxides may be referred to two pairs for each one, diopside being considered as split up into simpler molecules, and kaliophilite being disregarded on account of its excessive rarity. These pairs, one member of which has the highest and the other the lowest amount of silica, are as follows:

	Molecule	Base to Silica	Molecule	Base to Silica
Salic	Orthoclase, $KAlSi_3O_8$	1 : 6	Leucite, $KAlSi_2O_6$	1 : 4
	Albite, $NaAlSi_3O_8$	1 : 6	Nephelite, $NaAlSiO_4$	1 : 2
	Anorthite, $CaAl_2Si_2O_8$	1 : 2	Wanting	
Femic	Wollastonite, $CaSiO_3$	1 : 1	Akermanite, $Ca_4Si_3O_{10}$	4 : 3
	Enstatite, $MgSiO_3$	1 : 1	Forsterite, Mg_2SiO_4	2 : 1
	Ferrosilite,[1] $FeSiO_3$	1 : 1	Fayalite, Fe_2SiO_4	2 : 1
	Magnetite, Fe_3O_4	1 : 0		

Considering holocrystalline rocks alone, in accordance with these assumed orders of affinity of the bases for silica and for alumina, quartz would be formed only when there is an excess of silica over that needed to permit the existence of the higher silicated pair for each base present, when the lower silicated member would be absent. If there is insufficient silica for this, the potash will form orthoclase rather than leucite, the magnesia and ferrous oxide forming olivine rather than hypersthene, and soda forming nephelite rather than albite if necessary. On the basis of the assumed order of affinity for silica, melilite should be formed rather than nephelite; but it is found that this is not the case, melilite being notoriously much more rare than nephelite. This undeniable exception may be attributed (in great part at least) to the mass-action and the high stability of the complex pyroxene molecules, into which lime enters in preference to melilite. After the potash is satisfied, the soda would form albite

[1] Cf. Washington, *Professional Paper*, U. S. Geological Survey, No. 14 (1903), p. 90.

rather than nephelite, if there is silica enough, the magnesia and ferrous oxide remaining in olivine. Leucite should thus be formed only when there is insufficient silica for all of the potash to form orthoclase, even after all of the soda, magnesia, and ferrous oxide have been reduced to their lowest silicated conditions.[1] These relations are somewhat complicated by the presence of the diopside, magnetite, ilmenite, and other molecules; but, as they have been fully discussed elsewhere, further details are uncalled for.

The above-described behavior of the various oxides is the *normative* one; that is, the ideal result of the application of the assumed orders of affinity of the bases for silica and for alumina. It remains to be seen whether it is the *normal*[2] one or not; that is, whether the actual facts are in accordance with these assumptions, as regards the occurrence of leucite.

In this theoretical discussion we shall first consider the norms only, not the actual rocks, and we shall assume that there is neither an excess of alumina over the alkalies and lime (resulting in normative corundum), nor of alkalies over alumina (resulting in normative acmite or alkali metasilicates), so that alumina may be eliminated from consideration, as well as corundum, acmite, and alkali metasilicates. The possibility of the formation of kaliophilite will be disregarded, as well as the presence of such usually minor constituents as Cl, SO_3, TiO_2, P_2O_5, etc. The numerical relations of the various oxides will be expressed in the following pages as molecular ratios, so as to make them comparable chemically.

[1] It may be noted that, were the direction of affinity reversed, so that silica had an affinity for the bases, rather than the bases for silica, in the order named, the presumptive order of formation of the minerals would be the reverse of that described. On such a basis we would expect leucite to be formed in preference to orthoclase, then nephelite rather than albite, and hypersthene rather than olivine. On this assumption, therefore, leucite, nephelite, and hypersthene rocks should be more common than olivine ones, which is not the case, and leucitic and nephelitic rocks much more abundant relatively to feldspathic ones than these are known to be.

[2] On page 2 of the paper cited above Michel Lévy apparently considers that the term "normative" is synonymous with "normal," and he objects to it on the ground that the normative minerals are seldom normal ones. He has evidently overlooked our express statement of the distinction between the two words: "normative" being employed by us in the accepted English sense of "establishing or setting up a norm," while "normal" is recognized as having the meaning of "usual" or "common," and is therefore not used in this connection. (Cf. *Quantitative Classification* [1903], p. 147.)

The first problem before us, then, is the determination of the limits of variation in composition of all norms in which leucite does or does not occur in accordance with the principles laid down, and in holocrystalline rocks derived from which modal leucite should or should not be found. This problem is capable of exact mathematical statement and graphic expression.

As the simplest case we should consider first only the persalic, peralkalic, and perpotassic magmas—that is, those composed only of silica, alumina, and potash, the last two present in equal amount—so that the norms of these and holocrystalline rocks resulting from their consolidation would be composed either of quartz alone, quartz and orthoclase, orthoclase alone, orthoclase and leucite, or leucite alone. Such rocks are seldom met with, and their relations would be very simple. Furthermore, they form a limiting value of the next group to be discussed, so they will be dealt with later.

As the next simplest case we may assume that soda is present also in variable amount, the magmas being persalic and peralkalic, but the relations of the alkalies varying from perpotassic to persodic. On our assumption that potash has a greater affinity for silica than has soda, albite and leucite could not be present together in the norms, but these and the holocrystalline rocks derived from such magmas would be composed of quartz, orthoclase, albite, leucite, and nephelite, either alone or in all possible combinations, with the exception just stated. The general chemical composition of such magmas will be represented by the following equations:

$$a\mathrm{SiO_2}+b\mathrm{Al_2O_3}+c\mathrm{Na_2O}+d\mathrm{K_2O}=100$$
$$\mathrm{Al_2O_3}=\mathrm{Na_2O}+\mathrm{K_2O}$$

The variables here are the absolute amounts or percentages of silica, soda, and potash, and the ratios of silica to soda, silica to potash, and soda to potash. Any two of these may be selected as a basis for plotting, and in my paper on the rocks of the Roman comagmatic region the percentage of silica was used for the abscissas, and the ratio $\frac{\mathrm{SiO_2}}{\mathrm{K_2O}}$ for the ordinates. Indeed, all the data represented on Plates I and II have been plotted on these bases, Plate III being the equivalent, thus plotted, of Plate I, as will be discussed later.

This use of ratios which may vary from zero to infinity, however, leads to hyperbolic curves, complicating the relationships and introducing very serious and misleading distortion through the extension of the diagram to infinity in one direction, and is therefore disadvantageous.[1] Consequently, and at the suggestion of Dr. Cross and Professor Iddings, this basis of plotting has been abandoned, and the percentage of silica used for the abscissas and the percentage of potash for the ordinates, both being expressed molecularly. While the relation of silica to potash, an important factor in the question of the formation of leucite, is thus rendered not quite so evident, yet the diagrams gain in simplicity and intelligibility, and there is also the great advantage of dealing only with straight lines, thus immensely simplifying the calculations and the construction, as well as the comparison of the actual rocks with the theoretical data.

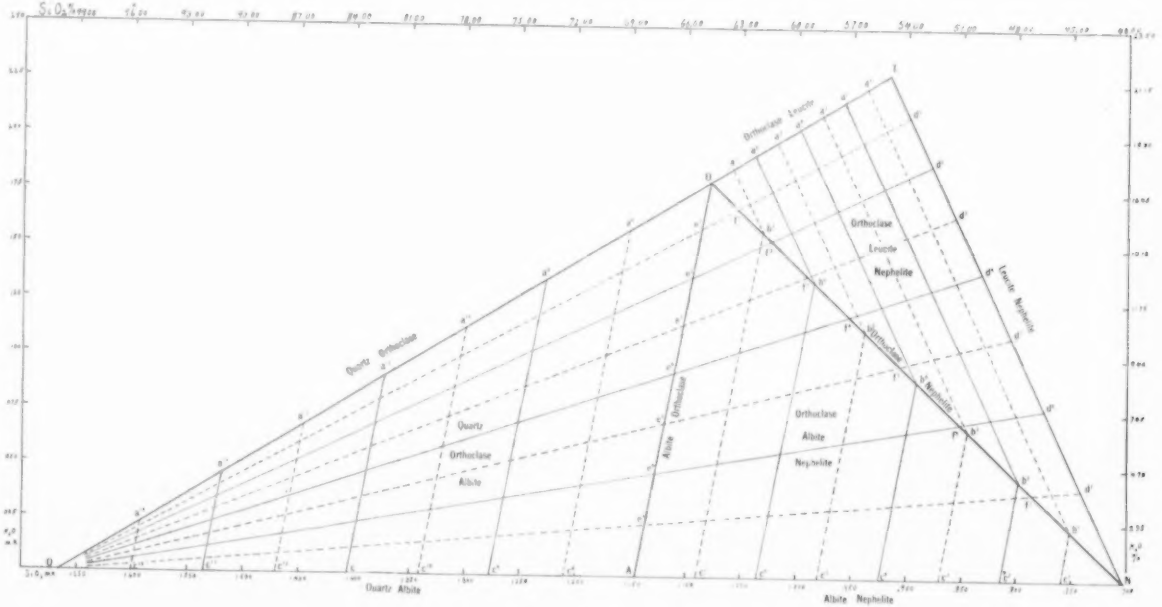
The calculation of any given magma is readily carried out by means of the equations already employed for the calculation of the center-points.[2] The results will be given in Table I at the end of this paper. Plotting these data for our assumed peralkalic and persalic magmas, with variable amounts of soda and potash, we obtain the results shown in Plate I. In this the solid lines are those passing through magmatic center-points, and the broken ones those passing through the border-points of the magmatic divisions. The purely sodic magmas lie along the bottom of the diagram, while the purely potassic ones are at the top. One hundred per cent of silica is at the left and zero at the right, as this is in accordance with the diagrams of Iddings and facilitates comparison with them. Furthermore, this corresponds with the order in which the various divisions are arranged in the *Quantitative Classification*.

It will be observed that these lines resemble those of Iddings[3] in some respects. The latter, however, employs for the ordinates the ratio $\frac{K_2O+Na_2O}{SiO_2}$, instead of the percentage of potash, and conse-

[1] Cf. Michel Lévy, *Bulletin de la Carte géologique de la France*, No. 92 (1903), p. 25.

[2] H. S. Washington, *Professional Paper*, U. S. Geological Survey, No. 14 (1903), pp. 84–87.

[3] J. P. Iddings, *Journal of Geology*, Vol. VI (1898), Plates IX and X; and *Professional Paper*, U. S. Geological Survey, No. 18 (1903), Plate II.


Orthoclase
Leucite
Nepheline
Quartz
Orthoclase
Albite
Leucite Nepheline
Orthoclase
Albite
Nepheline
Quartz Orthoclase
Quartz Albite
Albite Nepheline

quently obtains curves instead of straight lines. Furthermore, Iddings' first diagrams were constructed before the elaboration of the magmatic divisions of the quantitative system, so that the center-points and border-points of these are not considered, while in his later diagram the limits are given for the orders and rangs of potash-lime and soda-lime rocks, the alkalies being considered separately.

It may be pointed out that all such diagrams represent loci of chemical equilibrium, the lines or curves being those of definite combinations of the chemical or mineral constituents. They are analogous to the pressure-temperature, concentration-temperature, and other diagrams employed to represent physico-chemical equilibria. It may also be noted that, apart from considerations of simplicity, convenience, or intelligibility, it makes no difference whether ratios or percentages are chosen as bases for plotting. The relations will be evident in either case.

Turning to Plate I, the line LN is the locus of norms composed wholly of leucite and nephelite, passing through the center-points of the various subrangs of order 9 in a persalic and peralkalic magma. Pure leucite is found at L and pure nephelite at N. Between these extremes are varying mixtures of the two, the points for definite combinations, which correspond to the center-points and border-points of the subrangs, being indicated by the intersections with the solid and broken lines which slope down toward the left. To the right of or above this line no peralkalic and persalic norms can exist, since there will be insufficient silica to satisfy the alkalies unless kaliophilite is formed, and this molecule has been excluded from consideration. To the left of or below it there will be an excess of silica, so that either orthoclase or albite or both will be present.

The line OA is the locus of purely feldspathic norms, that is of the center-points of order 5, composed wholly of orthoclase and albite in varying proportions, pure orthoclase being found at O and pure albite at A, and the definite combinations which correspond to the center-points and border-points of the subrangs being indicated by the intersections with the solid and broken lines which extend upward toward the right. To the right of this line the norms must contain nephelite or leucite, or both of these, the maximum amounts being reached at the leucite-nephelite line LN, along which lenads alone

are found. To the left of the orthoclase-albite line OA there is an excess of silica over that needed for the feldspars, so that the norms must contain quartz.

Connecting O and L is the line LO, which is the locus of purely potassic norms (the ordinal center-points of subrang 1), consisting of varying amounts of orthoclase and leucite, from pure orthoclase at O to pure leucite at L. Below this line soda is present, forming either albite or nephelite, or both, while above it no norms can exist, for the reason to be mentioned presently.

Although irrelevant to the immediate discussion, the line OQ may be mentioned. This is continuous with LO, and is the locus of norms composed only of orthoclase and quartz in varying proportions, orthoclase occurring at O and quartz at Q. Above and to the left of this orthoclase-quartz line, as well as its continuation OL mentioned above, no norms can exist, since, for any given point in this region, the sum of the silica, alumina, and potash will be greater than 100 per cent if alumina and potash remain equal, or, if the necessary alumina is excluded, the potassium metasilicate molecule will be present, and this we have excluded from consideration. To the right of and below this line the norms will contain increasing and varying amounts of albite and nephelite, and decreasing amounts of quartz, until the orthoclase-albite line OA is reached, when quartz vanishes and to the right of which nephelite enters into the norm.

Within the area LOAN, therefore, are to be found all norms composed only of orthoclase, albite, leucite, and nephelite. The purely potassic ones will lie along the leucite-orthoclase line LO, and those richest in leucite toward the top of the area around the point L, while the purely sodic ones will be found along the albite-nephelite line AN, the albitic ones being around the point A. As albite and leucite cannot coexist in the norm, *ex hypothese*, it is clear that in one part of the area LOAN leucite must be present without albite, while in another part albite will be present without leucite, in each case in combination with varying amounts of orthoclase and nephelite.

The line separating these two is the line ON, which is the locus of norms composed only of orthoclase and nephelite in varying amounts, from pure orthoclase at O to pure nephelite at N. To the left of this the norms contain orthoclase, albite, and nephelite, but no

leucite; while to the right of it they contain orthoclase, leucite, and nephelite, but no albite.

This orthoclase-nephelite line ON is therefore a highly important one in our discussion, marking, as it does, one limit of leucitic norms, the others being the leucite-nephelite and leucite-orthoclase lines LN and LO, beyond which no norms can exist, as we have seen above. Within the leucite-orthoclase-nephelite area LON, therefore, must fall all leucitic peralkalic and persalic norms, and this may be called the *leucitic area*. Several features of this leucitic area deserve remark as bearing on the subsequent discussion. The first is the small size as compared with the feldspar-nephelite area OAN and the feldspar-quartz area OQA. Calling the area of the leucitic area of LON unity, that of OAN is 1.662, and that of OQA is 1.966. Or expressed in percentages of the whole area LQN they are as follows: LON = 21.61, OAN = 35.91, and OQN = 42.48.

The second feature is the shape and the position of the leucitic area—an acute-angled, almost isosceles, triangle, with the apex down and inclined sharply to the right. In consequence of this shape and position, the greatest variation in potash occurs at the silica percentage of leucite, S = 0.9194, and the greatest variation in silica at the potash percentage of orthoclase, K = 0.180. Therefore, as the percentage of silica of the magma falls below that of leucite, the possible range in potash rapidly diminishes till the silica percentage of nephelite is reached at S = 0.704, while as the percentage of silica of the magma rises above that of leucite the range in potash diminishes at a more rapid rate until the silica percentage of orthoclase is reached, above which no leucite can exist.

Crossing the whole area LQN are seen two sets of lines, one representing the loci of the center-points and border-points of the orders, and the others the center-points and border-points of the subrangs. The lines $a^1b^1c^1$, $a^2b^2c^2$, etc., are the loci of the different ratios of lenad to feldspar and of feldspar to quartz, corresponding to the center-points and border-points of the orders. The ordinal lines $a^1b^1c^1$ to $a^7b^7c^7$ are broken at the intersections b^1, b^2, etc., with the orthoclase-nephelite line ON, the lower limiting value of the leucitic area, while a^9c^9 to $a^{16}c^{16}$ are straight and continuous. This change in direction or refraction in passing out of the leucitic area follows

mathematically from the change in the norm. Starting from the top, where the magmas are perpotassic, increase in soda necessitates an increase in the amount of nephelite, this being the only sodic mineral present, and orthoclase being the only feldspar possible within the leucitic area. This brings about a decided decrease in the silica percentage, as that of nephelite is much less (42.25) than those of orthoclase (64.75) and leucite (55.05). On the other hand, left of the orthoclase-nephelite line ON, where the potash enters only into orthoclase and the relative amount of nephelite remains constant along the ordinal line, increase in soda necessitates an increase in the amount of albite. This causes a rise in the silica percentage, since that of albite (68.70) is higher than that of orthoclase (64.75).

The other set of lines, $d^1f^1e^1Q$, $d^2f^2e^2Q$, etc. are the loci of different ratios of potash to soda, corresponding to the border-points and center-points of subrangs. Since along these subrang lines the relation of potash to soda remains constant and the variation is in the amount of silica, an increase in silica causes an absolute decrease in the amount of potash, expressed by a slope of the line to the left. They are therefore straight and continuous, vanishing at the left in the point Q, which is the locus of pure quartz.

A study of the sizes and forms of the various areas included between the dotted lines corresponding to the limits of the various magmatic divisions of persalane (except the rangs, those here represented being all peralkalic) is of interest as showing the differences between these and their possible normative characters in different directions. But this is apart from our subject, and would lead us too far astray.

We have been dealing so far only with persalic and peralkalic magmas, in which only quartz, orthoclase, albite, leucite, and nephelite can form. But it is well known that such rocks are extremely rare, plagioclase feldspars and femic minerals entering into the norms of nearly all igneous rocks to a greater or less extent. To render our theoretical data adequately comparable with actual rocks, therefore, we must consider magmas which contain salic lime, and an equal amount of alumina, furnishing anorthite, and those which contain femic molecules, in both cases with varying amounts of silica and alkalies. It is clear that it would be a very complicated undertaking

to examine these fully, owing to the many combinations possible and the almost unlimited number of choices in the matter of variables, especially when the femic minerals are considered. But fortunately the calculation and presentation of a large number of hypothetical magmas is not necessary, and the general principles can be readily shown by a few typical cases.

Still adhering to persalanes, we may introduce anorthite and examine domalkalic and alkalicalcic magmas, that is, those in which the total alkalies are respectively, three times the amount of lime, and equal to it, corresponding to the center-points of the second and third rangs. The norms of these would contain quartz, orthoclase, albite, anorthite, leucite, and nephelite, in all possible combinations and amounts, except that albite and leucite would never occur together. These are represented on Plate II.

In Plate II the black lines represent the loci of persalic magmas, the green those of dosalic magmas, and the red those of salfemic ones. The orthoclase-quartz line OQ, and the feldspar-quartz area OQA, have been omitted as irrelevant to the discussion, but it is to be remembered that these quaric areas are always to be understood as existing, even though unrepresented. Also the lines which express the relations of feldspar to lenad (orders) and of potash to soda (subrangs) are omitted, as their presence would complicate the diagram with little compensating advantage. The dotted lines A^1L^1 and L^1M will be referred to subsequently. The small squares and circles represent the positions of actual rocks, and will be referred to subsequently. In the pages which follow, letters in italics, as *LON* for instance, indicate homologous points, lines, and areas in general, without specification of any particular kind of magma.

The solid black lines, marked L^1, O^1, etc., are the loci of persalic and *peralkalic* magmas, which have been treated above, and these are identical with the corresponding ones on Plate I. The black lines made up of long dashes, and marked L^2, O^2, etc., are the loci of persalic and *domalkalic* magmas; while those composed of short dashes, and marked L^3, O^3, etc., belong to persalic and *alkalicalcic* magmas.

Comparison of these three systems reveals some interesting relationships. The leucite-nephelite lines L^1N^1, L^2N^2, etc., and the ortho-

clase-nephelite lines O^1N^1, O^2N^2, etc., are very close together and parallel, this being due to the fact that in nephelite and in anorthite the relative number of molecules of silica to those of soda and of lime is the same in both(2 : 1),while the molecular weights of soda and of lime (62 and 56), and consequently of nephelite and of anorthite (284 and 278), are approximately the same. These lines, however, shift successively to the left or more siliceous end of the diagram with the introduction of the anorthite molecule, since the silica percentage of this is slightly higher than that of nephelite, 43.17 and 42.25 respectively.

On the other hand, the introduction of the anorthite molecule reduces the amount of potash present, so that the lines L^2O^2 and L^3O^3 are successively lower than the peralkalic line L^1O^1. They are also shifted successively toward the right or less siliceous end, owing to the low percentage of silica in anorthite. L^2O^2 and L^3O^3 are not parallel to L^1O^1, since they are continuous with the lines O^2Q and O^3Q, not shown in the diagram, these perpotassic borders ending in the common point Q. It will also be seen that the lines O^2A^2 and O^3A^3 are successively lower and more to the right than O^1A^1, this following from the considerations mentioned above.

It will also be of interest to examine the relative sizes of the various areas, the quaric areas *OQA* being also considered, as of possible interest, though not pertinent to the present discussion. The size relations are shown in the two succeeding tables, the first showing the relative sizes referred to the corresponding peralkalic area as unity, and the second in percentages of the whole area LQN.

It will be seen that, while the leucitic areas become successively smaller with increasing lime, yet that relatively to the feldspathic areas, *OAN*, they remain practically constant; this last relationship being due to the very slight shift in the diagram toward the left of the lines *LN* and *ON*. It will also be seen that, as lime enters, the leucitic area decreases, as does the feldspathic area, but that the quaric area increases, relatively to the whole amount of possible magmas.

All the above relations will, of course, be the same in direction, though differing in amount, if the magma is assumed to be docalcic, while if it be percalcic the areas will vanish in the point SiO_2 =

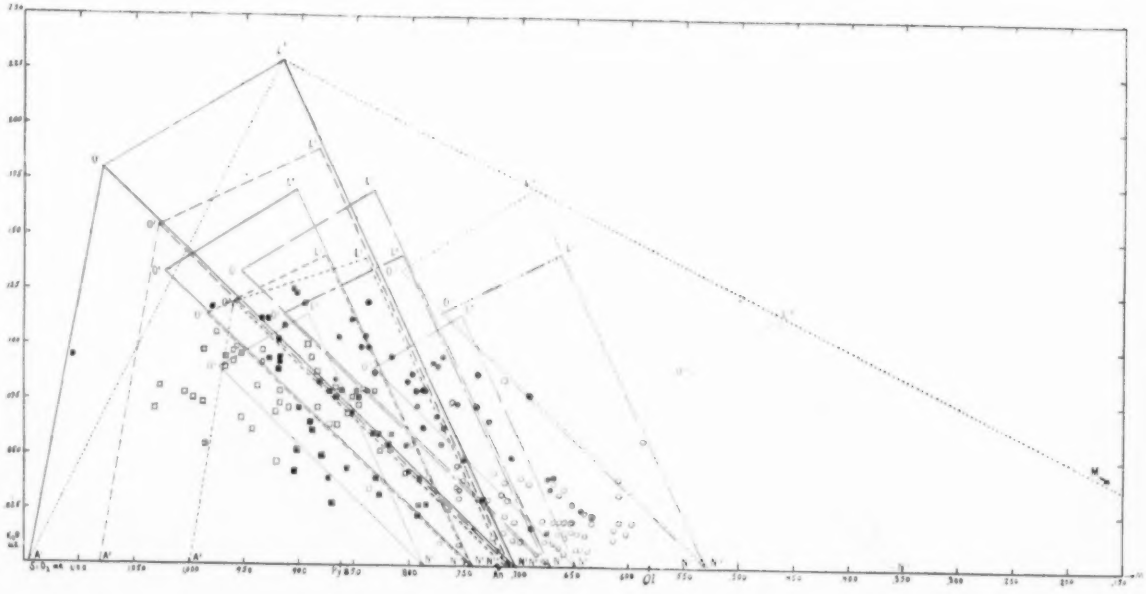


TABLE I

RELATIONS OF HOMOLOGOUS AREAS, REFERRED TO THE PERALKALIC AREA AS UNITY

Area	Peralkalic	Domalkalic	Alkalicalcic
LON	1.000	0.731	0.417
OAN	1.000	0.724	0.434
OQA	1.000	0.962	0.855
LQN	1.000	0.827	0.609

TABLE II

RELATIONS OF HOMOLOGOUS AREAS, IN PERCENTAGES OF THE AREA *LQN*

Area	Peralkalic	Domalkalic	Alkalicalcic
LON	21.61	19.11	14.78
OAN	35.91	31.45	25.60
OQN	42.48	49.44	59.62
LQN	100.00	100.00	100.00

0.719, along the abscissal axis, this being the molecular amount of silica in anorthite. This is also the point of intersection of lines drawn through L^1, L^2, etc., and through O^1, O^2, etc., with the line QN. Consequently all persalic leucitic norms will lie in the area $L^1O^1An\ N^1$.

From the above we may draw the following conclusions as to the influence upon the leucitic area of the introduction of anorthite into the magma. The possible range in potash for any magma with a percentage of silica greater than that of the corresponding mixture of leucite and anorthite will be decreased, while for silica percentages below this point there will be but little change. For homologous magmas, as regards order and subrang, the absolute amount of potash will decrease, while that of silica will also decrease down to a certain point, dependent on the magma, after which it will slowly rise.[1] As the amount of anorthite increases, the size of the leucitic area decreases, both absolutely and relatively to that of the whole area of possible norms, this decrease being increasingly great.

It is therefore clear that, in general, the introduction of anorthite into persalic magmas has little influence on the presence of leucite

[1] Compare the figures on p. 95 of *Professional Paper* No. 14, U. S. Geological Survey, 1903. Those for the more lenic orders are incomplete, as the compositions of the more calcic rangs of these, which cannot exist according to the definition of the respective orders, were not calculated.

in the norm, except when they are highly potassic, or unless the amount of salic lime exceeds that of the alkalies, when its influence will be increasingly felt.

We may now introduce femic molecules into the magma and see what influence they exert upon the presence of leucite. In order not to complicate the calculations unduly, we shall examine only a few simple, but typical, cases.

Let us first assume that the femic mineral is a standard, non-aluminous pyroxene exactly intermediate between diopside and hedenbergite—with MgO = FeO, and the formula $Ca(Mg, Fe)(SiO_3)_2$. The molecular weight of this is 232, and its silica percentage is 51.72, intermediate between that of orthoclase and those of nephelite and anorthite. We shall also assume that the magmas are centrally dosalic and salfemic—that is, with the amount of salic minerals in the norm three times that of the femic, and equal to it respectively. In the case of the dosalanes we may also consider the two cases in which the magma is either peralkalic or domalkalic. The variable factors then will be the relations of feldspar to lenads and of potash to soda, as in the previous cases. The lines which limit the leucitic areas in these norms are shown in Plate II, the peralkalic and domalkalic dosalanes respectively by solid and short-dashed green lines, and the salfemic magmas by solid red lines. The orthoclase-albite lines (*OA*) are omitted, as unnecessarily complicating the diagram. They may be drawn in, if desired, from the points *O* to *A*, parallel to the lines O^1A^1, O^2A^2, and O^3A^3.

Confining our attention, therefore, to the leucitic areas alone, it is evident that these are all identical in shape with those of the persalanes which are homologous as regards salic lime. The lines L^4N^4, L^5N^5, and L^6N^6 are parallel to L^1N^1, L^2N^2, and L^3N^3, and similarly the lines *ON* are all parallel to each other. On the other hand, the peralkalic L^4O^4 and L^6O^6 are parallel to the peralkalic L^1O^1, while the domalkalic L^5O^5 is parallel to the domalkalic L^2O^2.

With increasing amounts of pyroxene, the several leucitic areas become smaller, until they would vanish (for peralkalic magmas) in the pure assumed pyroxene at the point Py, where $SiO_2 = 0.862$ on the line QN, which is also the intersection point of lines drawn through the homologous points L^1, L^4, and L^6, and O^1, O^4, and O^6. Fur-

thermore, the areas are shifted successively toward the more siliceous end of the diagram, owing to the higher percentage of the pyroxene in silica than in nephelite, It will also be noted that the influence of the introduction of anorthite is exactly similar in character to that already noted in the case of the persalanes, though the change is less quantitatively, as shown by the lines L^4N^4 and L^5N^5, and O^4N^4 and O^5N^5, being closer together than was the case with the homologous lines in the persalanes. But it seems needless to go into greater details, as the principles will be the same as with the preceding cases.

We may next assume that the femic molecule is an olivine, exactly intermediate between forsterite and fayalite—that is, with MgO = FeO. The molecular weight of this is 172, and the silica percentage is 35.88. As in the preceding case, we shall consider both dosalic and salfemic magmas, and in the former shall assume the magmas to be peralkalic and domalkalic, while in the salfemanes only peralkalic ones will be considered. Pyroxene is assumed to be absent in all these cases.

The leucitic areas of these various olivinic magmas are shown in Plate II, the peralkalic and domalkalic dosalanes respectively by green lines made up of very long dashes and of the same with alternating short ones, while the salfemic magmas are represented by red lines made up of very long dashes. Here again the triangular leucitic areas are of exactly the same form and parallel to the homologous ones in the persalanes and the pyroxenic magmas, and, furthermore, the sizes of the olivinic areas are the same as those of the corresponding pyroxenic ones. Thus, $L^7O^7N^7$ is the same size as $L^4O^4N^4$, and $L^9O^9N^9$ as $L^6O^6N^6$, and so on. This, of course, is due to the fact that the relative amounts of potash in homologous magmas remains the same whether olivine or pyroxene is introduced. But it will be seen that the introduction of olivine, rather than pyroxene, shifts all these leucitic areas well toward the right, or less siliceous, end of the diagram, a consequence of the lower silica percentage of the olivine. Furthermore, as in the preceding cases, increase in the amount of olivine lessens the size of the triangle until, for perfemic magmas, they would vanish at the point Ol, where $SiO_2 = 0.598$ in the line QN, which is the locus of our assumed olivine, and which is also the intersection of lines passing through L^1, L^7, and L^9, and

through O^1, O^7 and O^9. Here also the influence of the introduction of anorthite is similar to that observed in the preceding cases, in the olivinic as in the pyroxenic salfemanes the lines LN and ON respectively falling so close together, in the otherwise homologous cases, as to be indistinguishable unless the diagram is drawn on a much larger scale than that used here.

Finally, we may introduce molecules of magnetite (without either pyroxene or olivine) into peralkalic and domalkalic dosalanes and peralkalic salfemanes. The leucitic areas of these are shown respectively by green lines made up of dots, and of dots and short dashes, and by red lines made up of dots. Here the shift toward the right or less siliceous end of the diagram is very pronounced, owing to the entire absence of silica from the femic mineral.[1] But the triangles are of exactly the same sizes as in the homologous cases just studied, and the homologous lines are all parallel. Furthermore, the leucitic areas become smaller and smaller absolutely with increase in magnetite, until they vanish at the point M, where $SiO_2 = o$, the locus of non-siliceous magmas, which lies to the right and outside of the diagram.

In the preceding cases we have assumed magmas of definite compositions, corresponding to certain center-points in the quantitative classification, as well as femic mineral molecules of simple and definite compositions and introduced singly. But it is clear that greater or less admixtures of anorthite or of femic molecules, or the introduction of several femic molecules simultaneously, will influence the positions of the various loci to a greater or less extent, but always in directions similar to those indicated by the examples given. Thus, if pyroxene and olivine, or pyroxene and magnetite, or all three, were assumed to be present in different proportions, the positions of the corresponding leucitic areas would lie between those of purely pyroxenic and purely olivinic or magnetitic ones, corresponding to the salic content, the exact position depending on the relative amounts and the compositions of the minerals present.

But in all cases—and this point is of great importance in the subsequent discussion when we come to deal with actual rocks—homolo-

[1] Apatite, ilmenite, corundum, or any other non-siliceous mineral would have, of course, the same effect as magnetite.

gous lines would be parallel to each other. Thus, the lines *LN* would be parallel to those here given, as would be the lines *ON* parallel to the lines *ON* of the diagram. It follows from this that the acute angle *LNO* of all possible leucitic areas would be the same, and also that the angles LNM^1 and *ONQ* would also be constant, so that the inclination of the triangular leucitic areas as regards the abscissal line QM would always be the same.

On the assumption that the kaliophilite molecule is excluded, it is also evident that all possible rock magmas must fall within the large triangle L^1QM, since outside of and above it there will be too much potash, as explained on a previous page (p. 272), and the points Q and M respectively represent pure quartz, or 100 per cent of silica, and pure non-siliceous mineral, or 0 per cent of silica.

As regards the sizes of the various leucitic areas, it is clear that, while they decrease absolutely with increase in anorthite or femic molecules, yet that relatively to the areas *OAM*, *OQA*, *LQN*, *LNM*, and *LQM*, corresponding in the relative amount of anorthite in any given case, they remain constant. This follows geometrically from the parallelism of the sides of the various homologous areas. Thus the ratio of the size of the salfemic and magnetitic leucitic area $L^{12}O^{12}N^{12}$ to the whole area $L^{12}Q^{12}N^{12}$ is the same as that of the persalic leucitic area $L^1O^1N^1$ to the whole area $L^1Q^1N^1$, since their homologous sides are parallel.

In general, therefore, the influence of the presence of anorthite and of standard, non-aluminous pyroxenes is to lower the percentage of potash without greatly disturbing the percentage of silica, or, in other words, to raise the ratio of silica to potash for the leucitic areas; while the presence of olivine molecules tends to lower this ratio to a less extent, the change being nil in the case of magnetite, and also to diminish to a much greater degree the percentage of silica in the magma, this reaching a maximum with magnetite.

In consequence of these relations, and those discussed in the preceding paragraphs, while with increase in femic minerals the leucitic areas extend on the whole toward the non-siliceous end of the diagram, so that eventually they cover the whole area to the right of the

[1] M is used to indicate the locus of magnetite where $SiO_2=0$ and $K_2O=0$, as explained above.

line O^1N^1, yet for any given set of magmas, homologous as regards the relative amounts of anorthite and given femic minerals, and variable only as regards feldspars and lenads and soda and potash, and consequently with fixed limits (*LQN*) for all possible magmas, there will be no disturbance of the ratios of the normatively leucitic ones and those normatively free from leucite.

From the above discussion and study of the diagrams, and on the assumption that potash has a greater affinity for silica than has soda or any other of the bases, we may draw the following conclusions as to the relations between the chemical composition of the magma and the formation of leucite, which are to be tested later by comparison with the data furnished by actual rocks.

1. There should be no leucitic rocks with an excess of silica over that necessary to bring all the bases to their highest silicated condition —that is, leucite should not occur in rocks whose norms show the presence of normative quartz.

1*a*). As a corollary to this we should never expect to find modally leucitic rocks with a silica percentage greater than 64.75, that of orthoclase; and as femic minerals and anorthite enter into the magma, the silica percentage of possible leucitic rocks should never exceed that of a mixture of orthoclase with the appropriate amounts of anorthite and femic minerals.

2. On the other hand, we can expect to find leucitic rocks with silica percentages running down to zero as a limiting value.

3. We should expect to find the greatest range in the percentage of potash consistent with the presence of leucite, and consequently the greatest number of leucitic rocks, with silica percentages about equal to those of mixtures of leucite and the appropriate amounts of anorthite and femic minerals. From these maxima the range in potash and the number of leucitic rocks should diminish slowly as silica falls, and should diminish more rapidly as silica rises.

4. We should not expect to find rocks without normative leucite carrying this mineral in the mode, and conversely we should expect rocks with normative leucite to carry this mineral modally.

4*a*). As a corollary to this it follows that, if the locus of a rock, expressed in terms of the percentages of silica and potash, and plotted as on Plate II, falls within the leucitic area corresponding to its char-

acters as regards anorthite and femic minerals, it should have leucite in the mode; while, if it falls outside of this area, it should be modally free from this mineral.

5. From the relative sizes of the leucitic and non-leucitic areas we should expect leucitic rocks to be much less abundant than non-leucitic ones.

6. We should not expect the presence of femic molecules in the magma to exert much influence on the presence of leucite, while the presence of anorthite should tend to lessen the probability of its presence, this influence being increasingly felt as the magma becomes more calcic.

Consequently we could expect to find leucitic rocks with very large amounts of femic molecules, but should not expect to find them with large amounts of salic lime, that is, when the amount of this exceeds that of the alkalies.

7. Other things being equal, there should be more probability of a rock being leucitic the higher the potash, while with increase in soda as regards potash the tendency toward the formation of leucite should diminish rapidly, so that we should not expect to find many leucitic rocks with soda in excess of potash.

There are given on Plate III the results of the data for persalic and peralkalic magmas plotted with the abscissas representing percentages of silica (but with 100 per cent to the right), and with the ordinates representing the ratios $\frac{SiO_2}{K_2O}$. Otherwise it is analogous to the diagram on Plate I. It is introduced because it is explanatory of my previous study of the subject, where this method of plotting was adopted, and because it is illustrative of the complexity introduced by the adoption of ratios rather than percentages as a basis for plotting, while the general relationships are still manifest. A brief description must suffice.

The lettering, and the signification of the lines and areas, on Plate III are the same as on Plate I; only it must be borne in mind that the directions, both up and down and right and left, are reversed, and that non-potassic and purely sodic magmas and normative minerals lie above the diagram at infinity, a serious distortion being thus introduced.

The line LN is that of pure lenad, leucite and nephelite, pure leucite being found at L and pure nephelite where the curve touches its asymptote[1] at infinity and where $SiO_2 = 0.704$. The line OA is that of pure feldspar, orthoclase being found at O, and albite where the curves become tangent at infinity with its asymptote at $SiO_2 = 1.145$. The curve LO is that of perpotassic magmas (leucite-orthoclase), and is continuous with the curve OQ, that of quartz and orthoclase, quartz being found at the point where the curve touches its asymptote at infinity and where $SiO_2 = 1.667$. The curve ON^1 is that of orthoclase and nephelite, orthoclase being found at O and nephelite where the curve touches its asymptote at infinity and where $SiO_2 = 0.704$, N and N^1 coinciding here.

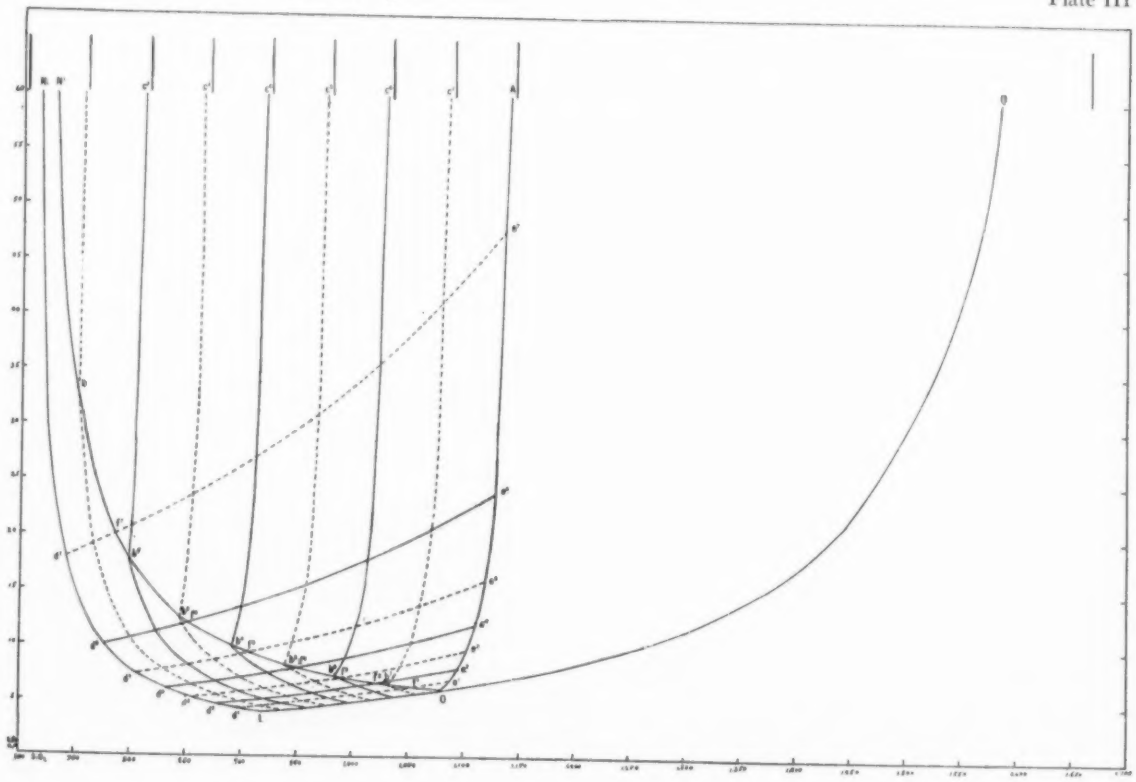
The leucitic area is therefore bounded by the curves LN, LO, and LN^1, N and N^1 rising and approaching each other with decreasing potash till they coalesce as just explained. The area N^1OA is that of orthoclase-albite-nephelite; and AOQ is that of quartz-orthoclase-albite, both of these extending upward to infinity. The whole area NLOQ, therefore, embraces all possible magmas, since outside of it no norms can exist, as already explained.

The ordinal curves are shown running down the diagram from top to bottom, and with well-marked cusps where they meet the orthoclase-nephelite curve N^1O, the angle of the cusp decreasing as the magma becomes more lenic. This change in direction is due to causes already explained. The curves representing subrangs run across the diagram from left to right. They are all continuous, but become successively steeper with increase in soda, for reasons referred to in a previous page.

Introduction of anorthite and of various femic minerals yield exactly similar homologous curves and areas, which have all been plotted, but which are omitted here. Their influence is quite analogous to that observed on Plate II. Thus the introduction of anorthite causes the curve LO to rise and shift successively toward the left with increasing lime, while the curves NL and N^1O are shifted to the right, but remain very close to each other.

But further description is unnecessary, and it may merely be

[1] The positions of these fixed asymptotes are indicated by the short straight lines at the top of the diagram.



pointed out that all the relations observable on Plates I and II, where the curves resolve themselves into straight lines, are fully manifest on a diagram plotted on this basis, though not so readily intelligible, owing to the distortion introduced.

APPENDIX I

LOCI OF LEUCITIC AREAS OF VARIOUS MAGMAS

No.	Character of Magma	O	L	N	
1....	Peralkalic persalane	1.079	.917	.704	SiO_2
		.180	.229	.000	K_2O
2....	Domalkalic persalane	1.028	.883	.708	SiO_2
		.154	.189	.000	K_2O
3....	Alkalicalcic persalane	.959	.840	.712	SiO_2
		.120	.140	.000	K_2O
4....	Peralkalic dosalane, with diopside	1.025	.904	.744	SiO_2
		.135	.172	.000	K_2O
5....	Domalkalic dosalane, with diopside	.986	.877	.746	SiO_2
		.116	.142	.000	K_2O
6....	Peralkalic salfemane, with diopside	.971	.890	.783	SiO_2
		.090	.115	.000	K_2O
7....	Peralkalic dosalane, with olivine	.955	.833	.673	SiO_2
		.116	.142	.000	K_2O
8....	Domalkalic dosalane, with olivine	.916	.807	.676	SiO_2
		.116	.142	.000	K_2O
9....	Peralkalic salfemane, with olivine	.830	.749	.643	SiO_2
		.090	.115	.000	K_2O
10....	Peralkalic dosalane, with magnetite	.809	.688	.528	SiO_2
		.135	.172	.000	K_2O
11....	Domalkalic dosalane, with magnetite	.771	.662	.531	SiO_2
		.116	.142	.000	K_2O
12....	Peralkalic salfemane, with magnetite	.540	.459	.352	SiO_2
		.090	.115	.000	K_2O

[*To be continued*]

THOMAS CONDON

CHESTER W. WASHBURNE
Chicago

The death (February 11, 1907) of Professor Thomas Condon ended a life little known among scientists, yet a life of considerable service to geology.

Professor Condon was an unusual man in that he seemed to have no desire to publish the results of his study. There are but few papers, only eight strictly geological, and one book, published over his name. But the writings of the scientists of his day—Le Conte, Dana, Marsh, Cope, and others— are full of references to Dr. Condon, and all of them acknowledge his contribution to science by exploration and theory.

Condon discovered the famous John Day beds which have so enriched our knowledge of Tertiary vertebrates. Here he found some of the specimens of three-toed horses on which Marsh based his theory of the evolution of that animal.[1] In this instance Marsh gave the discoverer scant credit for his work, and the type-specimens remained in Yale Museum until after Marsh died. The same thing happened to many other valuable specimens loaned to Marsh, Cope, Gabb, and others. A fine lot of Pliocene birds from southeastern Oregon, loaned to Cope, were never returned. It was doubtless to the interest of science that these fossils fell into the hands of other men, but it was unjust to Condon not to acknowledge more fully his services, and not to return his specimens. In 1867 Professor Condon printed in the *Portland Oregonian* an account of what he then thought to be the first fossil horses found in America, the same specimens that Marsh described several years later. What a strange contrast between these zealous, ambitious paleontologists, and that lonely, unselfish but no less devoted worker in the wilderness of Oregon!

Condon's best friend and occasional companion was Joseph Le Conte, who accompanied him on several trips, and who always gave

[1] Professor Henry F. Osborn has said: "I believe that Professor Condon deserves the entire credit of the discovery of the Upper Oligocene horses in the John Day." (*Pacific Monthly*, November, 1906, p. 566.)

him the fullest credit when publishing his ideas or observations. These two old lovers of earth-science recall a comparison made by Suess,[1] in writing of an almost unknown geologist, Arnold Escher von der Linth:

> On the one side stood Sir Charles,[2] the calm, superior philosopher, the lucid thinker and able writer; on the other, dear old Arnold Escher, who intrusted his admirable sketches and diaries to everyone indiscriminately, but to whom every line he had to publish was a torment, and who was perhaps only quite in his element up in the snow and ice, when the wind swept his gray head and his eye roamed over a sea of peaks.

From a scientific standpoint Professor Condon's best contribution is doubtless his paper[3] on "The Willamette Sound." Condon showed that this Pleistocene body of water filled the Willamette Valley, and extended north to Puget Sound, with a probable length of about three hundred miles. He worked out its extent and depth by means of terraces along the Columbia River and the ocean.

Professor Condon's book, *The Two Islands*,[4] is a popular account of the geological history of the original "Oregon country." The Klamath mountain group of southwestern Oregon and northern California was an island (Siskyou Island) in the Cretaceous sea, separated from the Sierra Nevada by Diller's Lassen Strait. The Blue Mountains, however, were not an island (Shoshone Island) at the time, for only in the Upper Cretaceous (early Chico) did the sea reach even the western part of the Blue Mountain region. But Condon's treatment of the subject brought out the striking geological difference between the two mountain groups and the rest of the state, showing that they are two regions of Paleozoic and Mesozoic rocks surrounded by Tertiary lavas and sediments.

Thomas Condon was born in Ireland, March 3, 1822. When he was eleven years old, the family moved to New York City; later to the central part of New York state, where Condon finished his education, taught school, and made a collection of New York paleozoic

[1] Preface to *Das Antlitz der Erde*, translation by Hertha Sollas.

[2] Sir Charles Lyell.

[3] "The Willamette Sound," *Overland Monthly*, Vol. VII, No. 5, pp. 468–73 (San Francisco, 1871); Reprinted as a chapter in *The Two Islands*.

[4] *The Two Islands and What Came of Them*. (Portland, Ore.: The J. K. Gill Co., 1904.)

fossils which later formed the nucleus of his splendid collection at the University of Oregon. He graduated from Auburn Theological Seminary in 1852, married Miss Cornelia Holt, and sailed for Oregon by way of Cape Horn.

For several years he had charge of the Congregational Mission at The Dalles, Oregon, then a small trading-post. It was while stationed at The Dalles that Condon made most of his trips into the interior, generally with military parties, gathering the fine Tertiary mammals in his collection. In 1872 he became professor of geology and natural history at Pacific University, resigning in 1876, to accept the same chair in the newly created University of Oregon. Here he remained until 1905, confining his teaching in later years mainly to paleontology. In these last years Professor Condon was too feeble to go into the field, but he had become so well known that people in all parts of the state were constantly sending him new specimens, knowing well the pleasure these gifts brought to the old naturalist who no longer could gather them himself. They were fresh links to the outdoor world, to the scenes of his early activities that he so enjoyed in memory.

Condon was one of those rare men that study science from an inherent love of nature, not merely for self-advancement, or for the praise of men.

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AEGIRITE AND RIEBECKITE ROCKS FROM OKLAHOMA

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Several years ago the writer spent a short time in studying and collecting the igneous rocks of the Headquarters Mountains in Oklahoma. An examination of the rocks some time afterward revealed the presence of aegirite and riebeckite, minerals which at the present time can scarcely be called rare, but are very interesting. Other occurrences of riebeckite in this country are: (1) granite of Quincy, Mass.;[1] (2) pegmatite of St. Peter's Dome, Colorado;[2] (3) paisanite, Paisano Pass, Texas.[3]

The Headquarters Mountain group comprises several low mountains at the extreme western border of the Wichita Range. The largest lies adjacent to and northwest of the town of Granite, Greer County, Oklahoma. There are several further to the northwest and a single one a little southeast of the town, all being west of the North Fork of the Red River.[4] These mountains like the others of the Wichita Range to the east rise abruptly from the level plain which give them an archipelago character.

THE COUNTRY ROCK

The main mass of these mountains is made up of a coarse-grained red granite. It weathers to large, rounded bowlders. Fresh specimens are very difficult to obtain as the ferro-magnesian constituents are almost invariably altered. The average size of the constituent minerals is about 7^{mm}. Under the microscope the rock is seen to be made up of orthoclase, albite, quartz, amphibole and zircon. The

[1] Washington, *Am. Jour. Sci.*, Vol. VI (1889), p. 180.

[2] Lacroix, *C. R.*, Vol. CIX (1889).

[3] Osann, *T. M. P. M.*, Vol. XV (1896), p. 437.

[4] For location see map, Plate II (opposite p. 54), "Professional Paper No. 31." *U. S. Geol. Surv.* On p. 58 of this paper a paragraph is given to description of this group of mountains. They are said to consist of red granite similar to that of the Wichita group.

orthoclase is intergrown with albite with characteristic twin lamellae appearing around the border or in the interior, thus forming microperthite, which is a characteristic feature of the rocks of this locality. An occasional Carlsbad twin occurs. The quartz is full of very minute inclusions. The amphibole is a dark-colored one with the following axial colors: **a**, brown, **b** deep greenish-blue, **c**, deep bluish-green. The extinction angle on (110)[1] is about 25°. The elongation is parallel to slower ray. It has the 124° cleavage of amphibole. Doubtless it is a soda amphibole, perhaps nearer hastingsite than any described mineral. Several small zircon crystals were discovered in the fragments of the crushed rock. Biotite was also noticed in some of the rock.

GRANITE-PORPHYRY, MICRO-GRANITE, ETC.

About half of the number of rock varieties collected are included under this heading. They grade from coarse granites with porphyritic tendency to fine-grained micro-granites, and are usually reddish or reddish-gray in color.

These fine grained micro-granites weather into rather angular bowlders.

The rocks are aggregates of quartz and orthoclase (often microperthite) with accessory amphibole, biotite, magnetite and apatite. The amphibole is sometimes riebeckite, sometimes one resembling that of the country rock. A rather peculiar intergrowth of quartz and orthoclase was noticed in one rock (No. 3). It may be described as an orthoclase mosaic in quartz. The quartz areas have uniform extinction over quite large areas, while the orthoclase areas only have uniform extinction over small areas. Thus it is neither a micropegmatitic nor micropoikilitic growth. One of the micro-granites occurs on the top of Mt. Walsh, the highest point of the Headquarters group. It is but a few feet thick and a little way down the slope the contact between it and the coarse granite may be seen.

APLITE VEINS

Perhaps the most interesting rocks of the region are the narrow dikes that cut the coarse granite, the country rock. About seven or

[1] Determined on cleavage flakes.

eight of these occur near the center of the largest mountain just northwest of Granite. They vary in width from one to sixteen inches. The prevailing color is a greenish-gray inclined to reddish-gray in places. The rocks are fine-grained with equidimensional constituents averaging about 1^{mm} in diameter. With a lens glassy grains of quartz, cleavable feldspars, black prismatic crystals (riebeckite), usually small but sometimes 3^{mm} in length, and minute greenish patches and needles (aegirite) can be recognized.

In thin sections these rocks are seen to be fine-grained mosaics of quartz, microperthite, and accessories with the typical panautomorphic texture of aplites. Both the feldspar and quartz have a tendency to assume a crystal form. The microperthite is an intergrowth of cloudy orthoclase with clear albite which is recognized by extinction angles and index of refraction. The albite occurs in patches within the orthoclase, on its border and in a few cases, independently. The orthoclase often occurs in Carlsbad twins. The quartz is xenomorphic to automorphic in various specimens. The best automorphic quartzes were hexagonal in outline though only a few of these were basal sections. The riebeckite, one of the accessory minerals usually occurs in large patchy aggregates so characteristic for this mineral, but in one rock (No. 12) it was in the form of small grains. Its color varies from green through a bluish-green and greenish-blue to deep, almost opaque blue. The axial colors are **a**, very deep blue; **b**, deep blue; **c**, green. $\mathbf{a} > \mathbf{b} > \mathbf{c}$. The extinction is practically parallel. In addition to cleavage parallel to (110), parting parallel to (010) was noticed. The aegirite varies from minute needles to small prismatic crystals with the octagonal cross-section characteristic of the pyroxenes. The pleochroism is yellowish-green to emerald-green, and the maximum extinction 5 or 6°. Magnetite and microcline are found in small amount.

The order of consolidation seems to have been first, the orthoclase, then the albite, next the aegirite and finally the quartz. The aegirite occurs as inclusions in the quartz (but not in the orthoclase), but mostly between the quartz and orthoclase. In one rock (No. 44) aegirite needles occur with their long axes parallel to outlines of the quartz. In this case it looks as though the quartz had simply pushed aside the aegirite, as there is no constant orientation due to

crystallization. Apparently the more abundant the aegirite is, the more abundant the albite.

An interesting case of alteration was found in one of the veins. Specimens of a vein some distance apart were collected before they were discovered to be the same rock. One of these (No. 44) was a fresh rock, greenish-gray color, with abundant crystals and needles of aegirite. The other specimen (No. 23) was gray with a dead look. The aegirite had disappeared and abundant magnetite had formed at its expense. The outlines of the aegirite crystals were filled with magnetite dust, and there were many large magnetite grains and crystals all through the rock.

RIEBECKITE PEGMATITE

At the foot of Main Street, in the town of Granite, near the base of the mountain, a pegmatite vein six and one-half inches (16^{cm}) wide was found. It occurs in the coarse granite and has a nearly east-west strike with dip toward the north. The striking thing about this rock is the occurrence of prismatic crystals two or three centimeters long and $\frac{1}{2}^{cm}$ in diameter. They have the six-sided cross-section of the amphiboles, and often appear with a central core of orthoclase. The other minerals are quartz, orthoclase and a little albite. The rock has the typical vein structure, for at the center is a band of fine-grained rock, on either side a zone of coarse-grained rock, and then on each side at the contact with the wall rock there is a band of fine-grained rock. Each of the bands is about 3^{cm} wide, but the vein is not quite symmetrical.

DIABASE DIKE

A short distance east by northeast of Mt. Walsh a fine-grained, black, basic dike, about four and one-half feet wide occurs. It has an east-west strike and almost vertical dip. The rock is exposed in a prospect shaft and is much altered. It consists of lath-shaped plagioclases, amygdules filled with a chlorite-like mineral (representing original ferro-magnesian mineral), and abundant magnetite. The rock has the typical ophitic structure, and so is a diabase.

An interesting thing about this dike is that it can be traced across the mountain by the character of the vegetation, though the rock is only exposed in one spot. The vegetation on the mountain is very

scant, but along the "lead" of this dike the vegetation is very abundant and a narrow strip of shrubs extends across the mountain.

These rocks are mostly soda rich as shown by the presence and comparative abundance of microperthite (orthoclase-albite), aegirite, riebeckite, and another soda amphibole of doubtful identity. A study of these rocks in connection with those of other parts of the Wichita mountain system, especially if chemical analyses were available, would probably give some very interesting results.

STUDIES FOR STUDENTS

THE RECENT ADVANCE IN SEISMOLOGY

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I. THE DISTRIBUTION OF SEISMICITY IN RELATION TO THE EARTH'S MOBILE BELTS

Introduction.—It is entirely safe to say that no period of equal length has registered so great an advance in the science of seismology as the decade now just brought to a close. The more important developments of this period may be broadly stated under three heads: (1) the determination of the laws of distribution of seismicity; (2) the discovery of a method for sensing and locating macroseisms through the body of the planet; and (3) the accumulation of so large a body of observational data as to advance from the condition of vague speculation to a well-grounded theory of the cause of earthquakes.

The laws of distribution of seismicity have been determined by a French officer of artillery, Count de Montessus de Ballore, whose thorough and conscientious work has occupied almost a lifetime. Rudolph had already, in 1887, made a most important contribution to the subject in a series of papers upon the distribution of seaquakes and submarine volcanic eruptions, which are supplementary to the studies by de Montessus. The discovery of new methods for studying at a distance the greater world-shakings is to be attributed, perhaps more than to anyone else, to the veteran English seismologist, Professor John Milne, who first started the great movement in Japan for seismological investigation, and since his return to England has been generously supported by the British Association for the Advancement of Science. The most modern and thoroughly equipped earthquake station today is, however, the German Chief Station for Earthquake Investigation at Strassburg, long directed by Professor Gerland, the founder of the International Seismological Association and the editor of its admirable

journal, *Gerland's Beiträge zur Geophysik*, in which appears the great annual catalogue of earthquakes.

The solid basis for the modern theory of causation of earthquakes must be credited in largest measure to the Austrian and Japanese schools of seismologists, though many outside these schools have made valuable contributions. Nowhere else in the world has earthquake investigation been carried to the same degree of well-planned refinement as in Japan, and nowhere is there a greater practical need for it. An admirable summary of Japanese achievements along this line is to be found in the recent work issued by the chairman of the famous Earthquake Investigation Committee.[1]

The distribution of seismicity.—The scientific investigations to determine the distribution of seismicity over the *land surface* of the globe may be said to have begun with the compilation of earthquake catalogues. The great catalogue of Perrey,[2] which fills six volumes, was a work which engaged an entire lifetime, and, full of errors as it is, has been the starting-point of all later work. More recently special catalogues have been prepared for particular seismic provinces; such, for example, as those of Milne for Japan,[3] Hoernes for Steiermark,[4] and Baratta for Italy.[5] It has remained for Count de Montessus de Ballore to devote the better part of his lifetime to collecting the scattered material now finally made available and by a process of correlation and standardization to lay the foundations for a new branch of the science—*seismic geography*.

The vast proportions of the work undertaken by the French savant above mentioned[6] will be appreciated when it is stated that the prob-

[1] D. Kikuchi, *Recent Seismological Investigation in Japan*, Pub. E. I. C. (foreign languages), No. 19 (1904), p. 120.

[2] Alexis Perrey, *Les tremblements de terre* (six volumes and a bibliography, Dijon, 1843–71).

[3] J. Milne, "A Catalogue of the Earthquakes Recorded in Japan between 1885 and 1892," *Trans. Seism. Soc. Japan*, Vol. IV (1895), pp. xxi+367, 2 pls.

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[5] M. Baratta, *I terremoti d'Italia* (Turin, 1901), pp. 960.

[6] F. de Montessus de Ballore, "Relation entre la rélief et la séismicité," *C. R. de l'Acad. des Sc. de Paris*, Vol. CXX (1895), pp. 1183–87.

——— "Introduction à un essai de description séismique du globe et mesure de la séismicité," *Beiträge zur Geophysik*, Vol. IV (1900), pp. 331–82.

——— "Loi générale de la repartition des régions séismiques instables à la sur-

lem which he set himself and carried to a most successful conclusion has been nothing less than the critical examination and cataloguing of all well-authenticated records of earthquakes to determine by a numerical figure the relative seismicity[1] upon a uniform scale of each earthquake province upon the globe; to prepare a composite map of epicenters for each; and, this once accomplished, to examine the topography and geology of each district with relation to its seismicity. No less than 170,000 separate shocks have thus been studied and placed in correspondence with each other.

His catalogue completed, de Montessus' first effort was to determine the relation of areas of high seismicity to the topographic relief. As a result, it is found that the seismic areas are throughout those of steepest general slope:

> In general, one may say that of two contiguous regions—for example, the two sides of a valley, the two flanks of a mountain chain, or plains and neighboring heights—the more unstable is that which presents the greater average slope, or the greater difference in altitude—that is to say, the greater relief either relative or absolute. The reason for this is without doubt that the relief is most frequently in consequence of the importance of dislocations; which, be it because of their lack of equilibrium, or because of the continuation of the tectonic movements which have caused them, quite naturally bring about earthquakes more easily.

The greater number of earthquakes, however, originate beneath the sea, and here, similarly, on the steep margins of the great oceanic deeps. For example, the scarp on the border of the great Tuscarora Deep has been the seat of much the larger number of destructive Japanese earthquakes. The vital question of the relation of earthquakes to volcanic activity, a dependence upon which was a quarter of a century ago the almost universal belief of geologists, is thus answered:

> Finally, while we may cite regions frequently shaken by earthquakes which at the same time have very active volcanoes, one should recognize the fact that

face du globe," *Berichte d. IIten international. Konferenz zu Strassburg, Beiträge zur Geophysik*, Ergänzungsband 2, 1903, pp. 325–34.

——— "Sur l'existence de deux grands cercles d'instabilité séismique maxima," *C. R. de l'Acad. des Sc. de Paris*, Vol. CXXXVI (1903), pp. 1707–9.

——— *Les tremblements de terre: Géographie séismologique;* avec une préface par M. A. de Lapparant; pp. v+475, 99 maps and figures, and 3 plates (Paris, 1906).

A brief account of the work of de Montessus and a list of his papers is given by F. M. Bernard ("Erdbeben Studien des Grafen de Montessus de Ballore," *Die Erdbebenwarte*, 1902, pp. 1–9).

[1] This term here implies both frequency and intensity of seismic shocks.

FIG. 1

Continent
Nord - Atlantique
Continent
pacifique
hypothetique
Continent
Africano - bresilien

FIG. 2

there is independence of the seismicity and volcanicity . . . . There is coincidence between the unstable regions and eruptions. . . . . But one phenomenon does not in a marked degree cause the other. This last negative law, which clearly results from the statistical researches, requires, however, a more detailed study. From all this we may conclude that, in general, earthquakes are a phenomenon purely geological, and that quite certainly they have their origin in dynamic causes by the effect of which the actual relief of the land is produced and of which they are the ultimate manifestation.

This conclusion of de Montessus is in harmony with that of Milne, who by an analysis of 10,000 earthquake observations in Japan showed that there were comparatively few which had their origin near to the volcanoes of the country.

As regards the broad distribution of the unstable areas upon the globe a most important law is discovered:

The earth's crust quakes in nearly equal amount and in a unique manner along two narrow zones which are disposed on two great circles (in the geometrical sense of the word), *which include between them an angle of about* 67 *degrees—the Mediterranean-Alps-Caucasus-Himalaya circle* (53.54 *per cent. of the shocks*) *and the circumpacific or Andes-Japan-Malay circle* (41.05 *per cent. of the shocks*). *These two zones coincide with the two most important lines of relief of the terrestrial surface.* . . . . . *The zones including the seismic regions coincide exactly with the geosynclinals of the secondary era*, as they have been charted by Haug in his well-known work, *Les géosinclinaux et les aires continentales. The geosynclinals (the most mobile zones of the earth's surface) where the sediments have been deposited in greatest thicknesses, have been energetically folded, dislocated, and re-elevated in the Tertiary period at the time of the formation of the principal actual ranges (or geoanticlinals); and include in themselves, with two or three doubtful exceptions, all the seismic regions* (in the sense which we have given to these two words) *which, in consequence, characterize them.*

Fig. 1, which has been reproduced with additional data from de Montessus' maps, indicates the position of the geosynclinals between the continental areas, and in black the seismic areas. De Montessus' latest work, from which these plates and the above extracts have been taken, has recently issued from the press.[1] This work is devoted to the study of the geological structure of the unstable regions of the globe, and follows as a natural sequel to the completed catalogue of seisms by the same author. The soul of the work, as he frankly admits, is to be found in the generalizations of Bertrand, de Lapparant,

[1] F. de Montessus de Ballore, *Les tremblements de terre: Géographie séismologique;* with a preface by M. A de Lapparant (Paris, 1906).

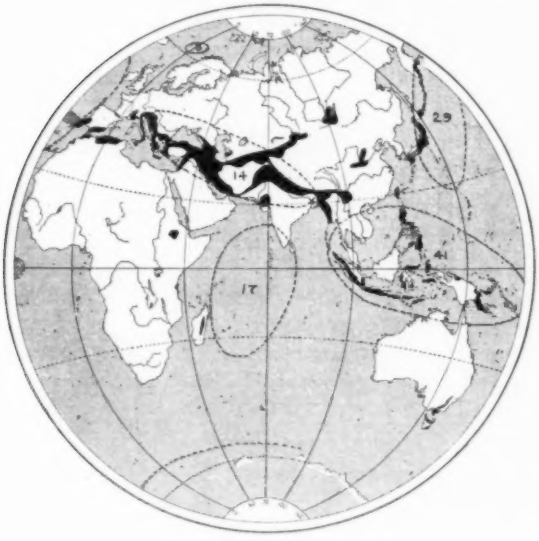
29
14
41
17

FIG. 3

Continent
Nord - Atlantique
Continent
sino -
sibérien
Continent
pacifique
hypothétique
Continent
Africano - brésilien
Continent
Australo - indo - malgache

FIG. 4

de Launay, and Suess; but the book is far more than a perfunctory comparison. It is only necessary to examine with care a few chapters to see that the author has given to each province conscientious study and has brought to his aid the latest researches of individual workers whose papers are not included in the generalizations of his predecessors. It is enough to say that the new volume constitutes a masterly work to which the future generation of geologists will find it necessary often to refer.

The earth's mobile zones.—The generalization of de Montessus, that the areas of high seismicity upon the earth's surface correspond in position to the geosynclinals as mapped by Haug,[1] makes it necessary that the valuable contribution of this savant be examined carefully. Wholly apart from this relationship, however, the paper is of great interest in itself, and should be especially so to Americans.

The conception of a geosynclinal is due to James Hall,[2] though the name was first applied by Dana,[3] who ascribed its folded structure to lateral compression, and not to the weight of the sediments, as did Hall. According to Hall, an enormous accumulation of sediments has followed certain zones of the earth's surface through gradual depression of the sea-floor along these belts; his law being that *the line of greatest depression coincides with the line of greatest accumulation*, a proportion being thus established at each point between the thickness of sediments and the amount of depression. The mountain chains form over the geosynclinals, a classical example being furnished by the Appalachian system. These generalizations Suess has supplemented by showing that within the folded regions the sedimentary series is generally complete and has a certain pelagic character, whereas in the unfolded districts one finds lacunae and intercalations of brackish water deposits.[4]

While Hall insisted that most of the sediments of the geosynclinals had their origin in shallow water, Suess referred to them as having a certain pelagic, and Neumayr even an abyssal, character. Haug's

[1] Emile Haug, "Les géosynclinaux et les aires continentales," *Bull. Soc. géol. France*, 3 Ser., Vol. XXVIII (1900), pp. 617–711.

[2] James Hall, *Nat. Hist. of New York: Paleontology*, Vol. III, p. 70 (Albany, 1859).

[3] J. D. Dana, *Manual of Geology* (2d ed., 1875), p. 748.

[4] Ed. Suess, *Die Entstehung der Alpen* (1875), p. 98.

view is that these sediments were deposited in a depth between that of the shallows and that of the deep sea (more definitely between depths of 80–100 and 900 meters)—a zone to which he has applied the name *bathyal*. Within this zone the geological rock formations are chiefly shales, clays, marls, schists, and compact and nodular limestones; and Haug finds a strong analogy between the distribution of fossils in rocks of this class which were formed during the Secondary era and the distribution of living forms within the bathyal zone of the ocean.

Hall's theory, which regarded the sediments of the geosynclinals as having originated in shallow water, required a most perfect equilibrium to exist between the rate of depression and the rate of accumulation; provided the same lithologic character was to be maintained for great thicknesses; but this adjustment is less necessary if greater depths of the floor of deposition be assumed. Haug expresses the view that in the vast majority of cases a correspondence exists between the axes of folds subsequently developed in a geosynclinal and the axis of the geosynclinal itself, instancing many French examples.

It is, however, the geographical distribution of the geosynclinals and their relation in position to former continents, in which the original contribution of Haug chiefly consists:

> The American authors, to whom is due the notion of geosynclinal, have always taken as the point of departure of their orogenic theories the fundamental idea that mountain chains form on the border of the oceans and that the continents increase by the addition of new chains successively more recent. According to this hypothesis, the geosynclinals should be born at the margin of the continents and the oceans, and should be exclusively of littoral sediments, and the zone of depression where the intensive sedimentation is going on should be separated from the high sea by a mere swell (*bourrelet*). It is easy to demonstrate that it is not under these conditions that the geosynclinals form; and that, far from originating at the margin of the oceans, they are always situated between two continental masses and constitute the mobile zones between masses relatively stable.[1]

As special cases in point the Himalayas and the mountain chains of central Europe are cited, and the general law is thus stated:

> (1) *The geosynclinals, the essentially mobile regions of the earth's crust, are always situated between two continental masses, the regions relatively stable;* (2) *the geosynclinals constituted before their filling marine depressions of a very considerable depth.*[2]

[1] *Loc. cit.*, p. 630. [2] *Ibid.*, p. 632.

After a discussion of the geosynclinals of the different geologic periods, it is added:

> Thus follows, even into the details, the conformity of the geologic history of the regions which have been affected by the large foldings of the Tertiary epoch, with those which have been occupied by the geosynclinals during all the Secondary era. If, in certain cases, one finds that the sinuosities described by the geosynclinals have not always been the same during two consecutive epochs, it is none the less true that they are always the same large regions which, since the beginning of Primary time, have been the mobile portions of the earth's crust.[1]

As regards, now the continents which have been separated by the geosynclinals, Haug states:

> It results from the summary given that zoögeographic works in all points confirm the conclusions relative to the existence of ancient continents quite different from the actual ones—conclusions obtained before by purely geological considerations. By a series of deductions borrowed from zoögeography we are led to admit the former existence of a *North Atlantic Continent*, of a *Sino-Siberian Continent*, of an *Australo-Indo-Malay Continent*, and of a *Pacific Continent*.[2]

Under the head of the breaking-up (*morcellement*) of the continents, Haug treats of this as having in some cases been accomplished by a gradual transgression of the sea; in other cases, by the production of vertical faults along which blocks of the crust have been depressed to produce abysses (the horsts remaining in relief); and in still other cases, by the depression of a continent in its entirety, so that a basin now occupies its former position, which is bounded by peripheral fractures marked out by volcanoes.

After an extensive study of stratigraphic documents with a view of fixing the positions of areas of transgression and recession of the sea, Haug argues that, if these are to be ascribed to the attraction of the glacial ice or to variations in the velocity of rotation of the planet, there should be alternations of transgression and recession between the polar and the equatorial regions, and also between the two hemispheres. He finds:

> (1) *The principal transgressions of the sea are produced simultaneously in the two continents.* (2) *They are produced simultaneously in the polar and equatorial regions.* (3) *They are not universal.*

[1] Ed. Suess, *Die Entstehung der Alpen*, p. 642.

[2] *Ibid.*, pp. 663, 664.

To these generalizations is added the positive one:

Whenever a definite member of the sedimentary series is found in transgression upon the continental areas, the same member will be in recession in the geosynclinals;

and reciprocally:

Whenever a member is found in transgression within the geosynclinals, it will be in recession upon the continental areas.[1]

It should be understood that the views of Haug above expressed set forth the attitude of a particular school of geologists; which views are opposed, as the quotations from Haug indicate, by those geologists who accept the doctrine of continental permanence.

[1] *Ibid.*, p. 682.

Reviews

Die kristallinen Schiefer. By Dr. U. Grubenmann. Vol. I, 1904; Vol. II, 1907. Zurich.

The recent work of Dr. Grubenmann, *Die kristallinen Schiefer*, Vol. I, aims, as its author states in the preface, to explain the characteristics of the crystalline schists, and their occurrence in the crust of the earth, according to chemical-physical laws. Although restricted to one phase of metamorphism, the motive of the work has much in common with *The Principles of Metamorphism* by Dr. C. R. Van Hise. Its general conclusions are, however, quite different.

Dr. Grubenmann briefly follows the historical evolution of conceptions relating to the origin of the crystalline schists, and discusses the original materials of the schists, and their specific characteristics. The cited criteria of sedimentary origin are: stratification, fossil record, micro- and megafragmental relicts, conglomerates, ripple-marks, delta formations, gradation phases, chemical composition, and abrupt changes in mineralogical composition within very narrow limits. The criteria given for igneous origin are: chemical composition, gradation phases, and the preservation of original forms of occurrence such as dikes, sills, stocks, and laccoliths.

The processes enumerated by which the original materials are metamorphosed into crystalline schists are mechanical reconstruction, recrystallization, and remineralization. The factors which, in conjunction with time, enter into these processes are solvents, heat, pressure, and the specific characteristics of the original materials.

Dr. Grubenmann makes a threefold division of the crust of the earth into an upper, middle, and lower zone, based on the predominance of one or more of the factors of metamorphism. The belt of weathering (Van Hise) is excluded from the upper zone.

The conditions named for the upper zone are moderate temperature and low hydrostatic pressure, positive heat-toning,[1] and powerful stress. The predominant pressure effect is mechanical. Heat liberation and decrease of volume result from the chemical reactions. The abundance of water favors the development of hydroxide minerals, such as sericite,

[1] The "heat-toning" of a reaction is positive when the sum of the resulting heats of formation exceeds the sum of the heats of formation of the vanished molecule.

chlorite, talc, zoisite, and epidote. These minerals, with quartz and calcite, form the characteristic rocks of this zone—namely, sericite-phyllite, sericite-quartzite, lime-phyllite, albite-phyllite, talc, and chlorite-schists, etc.

The conditions named for the middle zone are higher temperature and intense stress, stronger hydrostatic pressure, and positive and negative heat-toning. The predominant effect of pressure is recrystallization and remineralization with decrease in volume. The minerals assigned to this zone as characteristic are biotite, zoisite, epidote, hornblende, staurolite, garnet, disthene, titanite, magnetite, ilmenite, muscovite, microcline, albite, and oligoclase. The typical rocks of this zone constitute the great mass of the crystalline schists: mica-schists, amphibolites, garnet, and staurolite-schists.

The specified conditions of the lowest zone are enormous hydrostatic pressure and high temperature, very feeble stress, and negative heat-toning. The reactions are inferred to take place with volume increase, since the minerals of this zone nearly all belong to Löwinson-Lessing's "plus" group. ("The molecular volume of the minerals of the plus group exceeds the molecular volumes of the oxides which compose them.") Dr. Grubenmann argues from this that the reactions are probably controlled by temperature and not by pressure. The minerals which are described as peculiar to this zone are cordierite, magnetite, sillimanite, ilmenite, orthoclase, plagioclase, biotite, augite, olivine, and garnet. The gneisses constitute the predominant rocks.

A number of mineral and rock alterations are cited as peculiar to each zone. Olivine of the lowest zone becomes hornblende or garnet in the middle, and serpentine in the upper zone. Granulation of grain, chloritization, and sericitization occur in the upper zone. An aluminous sediment composed of kaolinite, quartz, mica, feldspar, iron oxide, and lime becomes a phyllite in the upper zone, a mica schist in the middle, and a gneiss containing feldspar, sillimanite, and other anhydrous minerals, in the lower zone.

Dr. Grubenmann's threefold division is not intended to apply to all the lithosphere with regard to metamorphic processes, since it is concerned with the development of the crystalline schists only. In a broad way, the three zones collectively correspond to Van Hise's zone of anamorphism and rock-flowage. Anyone who has made a field study of the crystalline schists appreciates the difficulty of classifying them according to the metamorphic processes to which they owe their origin, since no direct observational evidence can be obtained to form the basis of such a classification. Although Dr. Grubenmann refers to the occurrence of schist zones in

certain truncated anticlines, and infers their order of superposition, the reader finds, as a whole, that the field evidence on which his threefold classification is based does not stand out very clearly. In fact, the reader gathers the impression that the threefold classification is based rather on inferences drawn from certain mineral associations than on decisive field observation of the existence of three zones.

Dr. Grubenmann infers that the reactions in the two uppermost zones occur with volume-decrease, since the characteristic minerals of this zone mostly belong to Löwinson-Lessing's "minus" group; i. e., their molecular volume is less than the molecular volume of the oxides which compose them. Most of his readers will probably not agree to this method, but will consider the actual volume-changes involved in the mineral alterations. Various investigators have shown that the alterations described as peculiar to these zones—chlorization, serpentinization, and sericitization—generally involve increase of volume.

In the lower zone also he considers the molecular volume relations between the minerals and their constituent oxides as indicative of the volume-changes caused by the reactions. He argues that the occurrence of "plus" minerals, like orthoclase, plagioclase, and sillimanite, indicates volume-increase. However, calculations of the actual mineral volume-change involved in their formations from other minerals show a decrease in volume.

In the second volume Dr. Grubenmann distinguishes twelve groups on the basis of chemical composition, which are delimited by empirically derived chemical values. The groups take their nomenclature from the rock formations which are peculiar to them. They are: (I) orthoclase gneisses, (II) alumino-silicate gneisses, (III) plagioclase gneisses, (IV) eklogite and amphibolite, (V) magnesian-silicate gneisses, (VI) jadeite rocks, (VII) chloromelanite rocks, (VIII) quartzitic rocks, (IX) lime-silicate rocks, (X) marbles, (XI) iron-oxide rocks, and (XII) alumino-oxide rocks. Each group is subdivided into orders, which are based on the physical characteristics assumed by a group in the upper, middle, and lower zone respectively. A group-name takes the prefix "kata" when it designates a rock of the first order or of the lowest zone. The prefix "meso" is applied to rocks of the middle zone or the second order; and the rocks of the third order or the upper zone take the prefix "epi." Frequently the orders are subdivided into families, based on mineral composition.

The first step in identifying the position of a crystalline schist in Dr. Grubenmann's system is to ascertain its chemical composition. The per-

centage weights of TiO_2 and P_2O_5 are converted into their equivalent weights of SiO_2 and added to the latter. In the same way Fe_2O_3 and MnO are added to FeO, and BaO and SrO are united with CaO. H_2O is neglected. The seven oxides resulting from this elimination are recalculated on a basis of 100, and then converted into molecular percentages. The molecular percentages are then distributed as follows:

S = molecules of SiO_2.
A = sum of molecules of $K_2O + Na_2O$ united with Al_2O_3 in the ratio of 1:1.
C = CaO united to Al_2O_3 in the ratio of 1:1.
F = sum of FeO and MgO. If Al_2O_3 is deficient, the remaining CaO is added to F.
M = CaO added to F.
T = excess of Al_2O_3 after satisfying CaO and the alkalies in the ratio of 1:1.
$K = \frac{Sio}{6A+2C+F}$.

These seven so-called group values, S, A, C, F, M, T, and K, are the "empirically derived chemical values" which delimit the groups. Besides these values, Dr. Grubenmann has adapted[1] Osann's[2] projection values, a, c, f, to the chemical classification of the crystalline schists.

The determination of the texture, structure, and mineral content of the schist completes the examination necessary for the complete identification of a schist according to Dr. Grubenmann's system.

Dr. Grubenmann does not claim to have produced a perfect system of classification. The zonal conceptions, he admits, are not entirely free from well-founded objections. A separation into two zones, he believes, would in many cases be more in accord with the facts of occurrence.

Die kristallinen Schiefer may be regarded as an excellent summary of known facts relating to the crystalline schists. It also contains new material. With present incomplete knowledge it is not possible to say whether the proposed classification is warranted and supported by the facts in the field. Perhaps its greatest service to the science consists in proposing a new theory which points out the necessity of a far more detailed investigation of the crystalline schists than has been made thus far.

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[1] See *Tschermark's mineralogische und petrographische Mittheilungen*, Vol. XIX, p. 351.

[2] $a = \frac{20A}{A+C+F}$; $c = \frac{20C}{A+C+F}$; $f = \frac{20F}{A+C+F}$.

The Copper Deposits of the Robinson Mining District, Nevada. By ANDREW C. LAWSON. (University of California Publications, Bulletin of the Department of Geology, Vol. IV, No. 14 [May, 1906] pp. 287–357.)

Many thousands of feet of Cambrian to Carboniferous rocks are exposed in this region. They lie in open folds, and in them are igneous intrusions of post-Carboniferous, probably mid-mesozoic age, and also later intrusions, probably Tertiary. These latest intrusions are of a light-colored, acid, porphyritic rock, and the ore bodies occur usually in them. The ore is low grade, but extensive.

The earlier intrusives are of especial interest in that, while they are post-Carboniferous, the author considers them of the same age as numerous other similar batholiths of the Basin Ranges usually considered archean.

E. W. S.

Water Powers of Northern Wisconsin. By LEONARD S. SMITH. (Water Supply and Irrigation Paper No. 114, U. S. Geological Survey, 1906.) Pp. 145; 5 plates, 5 figures.

Water power is an especially important subject in Wisconsin, because that state is so distant from coal-supply. Mr. Smith points out that the available unused water power is considerable, and makes estimates as to its exact amount. The physical geography and drainage are discussed. A wide highland, 1,000–2,000 feet above the sea, crosses the northern part of the state, from which the drainage goes out in all directions.

E. W. S.

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THE JAMES D. DANA MONUMENT, DANA PARK, ALBANY, N. Y.